Element B

Washington State's Overview, Risk Assessment, and Natural Hazard Profiles,

Requirement §201.4(c)(2)	[The plan must include] risk assessments that provide the factual basis for activities proposed in the strategy portion of the mitigation plan. Statewide risk assessments must characterize and analyze natural hazards and risks to provide a statewide overview. This overview will allow the State to compare potential losses throughout the State and to determine their priorities for implementing mitigation measures under the strategy, and to prioritize jurisdictions for receiving technical and financial support in developing more detailed local risk and vulnerability assessments. The risk assessment shall include the following:
§201.4(c)(2)(i)	An overview of the type and location of all natural hazards that can affect the State, including information on previous occurrences of hazard events, as well as the probability of future hazard events, using maps where appropriate;
§201.4(c)(2)(ii)	An overview and analysis of the State's vulnerability to the hazards described in this paragraph (c)(2), based on estimates provided in local risk assessments as well as the State risk assessment. The State shall describe vulnerability in terms of the jurisdictions most threatened by the identified hazards, and most vulnerable to damage and loss associated with hazard events. State owned or operated critical facilities located in the identified hazard areas shall also be addressed;
§201.4(c)(2)(iii)	An overview and analysis of potential losses to the identified vulnerable structures, based on estimates provided in local risk assessments as well as the State risk assessment. The State shall estimate the potential dollar losses to State owned or operated buildings, infrastructure, and critical facilities located in the identified hazard areas.
§201.4(d)	Plan must be reviewed and revised to reflect changes in development, progress in statewide mitigation efforts, and changes in priorities and resubmitted for approval to the appropriate Regional Administrator every three years.

Requirement §201.4(c)(2)(i) - An overview of the type and location of all natural hazards that can affect the State, including information on previous occurrences of hazard events, as well as the probability of future hazard events, using maps where appropriate;

Requirement §201.4(c)(2)(ii) - An overview and analysis of the State's vulnerability to the hazards described in this paragraph (c)(2), based on estimates provided in local risk assessments as well as the State risk assessment. The State shall describe vulnerability in terms of the jurisdictions most threatened by the identified hazards, and most vulnerable to damage and loss associated with hazard events. State owned or operated critical facilities located in the identified hazard areas shall also be addressed;

Requirement §201.4(c)(2)(iii) - An overview and analysis of potential losses to the identified vulnerable structures, based on estimates provided in local risk assessments as well as the State risk assessment. The State shall estimate the potential dollar losses to State owned or operated buildings, infrastructure, and critical facilities located in the identified hazard areas.

Introduction[1]

Washington is one of the Pacific states of the United States of America. It is bounded on the north by the Canadian province of British Columbia, on the east by Idaho, on the south by Oregon, and on the west by the Pacific Ocean.

A series of marine channels in the northwest – the Strait of Juan de Fuca, Haro Strait, and the Strait of Georgia – separate the state from Canada's Vancouver Island. Puget Sound deeply indents the northwestern part of the state. These bodies of water contain numerous islands that form part of the state. The Columbia River forms much of the southern boundary.

The terrain of the state is extremely varied, including mountain ranges, forests, plateaus, lowlands, and small islands. The Cascade Range runs north to south bisecting the state. From the Cascades westward, the state has a predominately marine west coast climate while east of the Cascades has a relatively dry climate.

Formerly known primarily for its agricultural and forestry products, by the early 1990s Washington State had developed a highly diversified economy. Although the state remained a leading national producer of products such as apples, wheat, and timber, manufacturing had become a leading sector of the economy. Tourism and other services also were important; the state's diverse scenic wonders attract hundreds of thousands of visitors annually. The largest employers in the state include the U.S. military, Boeing, Microsoft, University of Washington, and the state government.

The state is comprised of 39 counties. George Washington is the state's namesake; the state's nickname is the Evergreen State.

The following sections provide a summary of the state's profile on key indicators hinting at the state's subjective ability to weather a disaster and bounce back. This is not a formal capability assessment or a resiliency methodology but it does inform the risk assessment done in the hazard profiles listed later. The summary starts with the geography, moves to economic considerations, and ends with the state's demographics.

Overall, Washington State's geography provides some significant benefits like diverse landscapes, abundant recreational opportunities, ample natural resources, and deep water ports. However, the state's geology and location exposes it to significant natural hazards. Nonetheless, the state's economic activities and demographics put it into the top 15 states in the country on various ranking methodologies. However, just in time inventory processes using an infrastructure system with multiple chokepoints where single point failures occur, can have detrimental if not disastrous consequences on the economic vitality of the state. As a result, people in the state may be more vulnerable to a disaster's impact than a quick scan of the statistics.

Figure 1. State of Washington Topographic Map

State Economic Profile

Requirement 44 CFR §201.4(c)(2): *Overview*. [The plan must include] risk assessments that provide the factual basis for activities proposed in the strategy portion of the mitigation plan. Statewide risk assessments must characterize and analyze natural hazards and risks to provide a statewide overview. This overview will allow the State to compare potential losses throughout the State and to determine their priorities for implementing mitigation measures under the strategy, and to prioritize jurisdictions for receiving technical and financial support in developing more detailed local risk and vulnerability assessments.

All things economic have their roots in the geography of the area.

Geography

Washington State's 66,582 square miles make it the 20th largest state in the country. The state is roughly half the area of Japan, three quarters the size of Great Britain, and about 40 percent the area of California. It is roughly rectangular, with dimensions of 235 miles from north to south and 345 miles from east to west. Elevations range from sea level to 14,410 feet at the summit of Mount Rainier. Washington's coastline on the Pacific Ocean is 157 miles.

The western section of Washington is part of the Coast Range region. In the southwest, the mountains, known locally as the Willapa Hills, form the lowest segment of the Pacific Coast range; the highest elevation here is about 3,110 feet. By contrast, the Olympic Mountains, which lie north of the Chehalis River valley, have some of the highest elevations in the Pacific mountain system. Mount Olympus, the highest peak, reaches 7,954 feet. With their deep glacial valleys and snowcapped summits, the Olympic Mountains offer some of the most spectacular scenery of the Coast Range.

To the east is the Puget Lowland, a structural depression that extends the length of the state. The maximum elevation is about 500 feet, and the surface is generally flat, although in places marked by hummocky glacial deposits. Puget Sound penetrates more than half of the basin's length.

The rugged, geologically complex Cascade Range lies east of the Puget Lowland. From the vicinity of Mount Rainier southward, the Cascade Range is a volcanic tableland, studded with cones including Mount Adams and Mount St. Helens. The northern section of the range is primarily a granitic mass that includes the most extensive valley glaciers in the lower 48 states; the state's two other volcanoes, Mount Baker and Glacier Peak, are found here. The 1980 eruption and subsequent activity of Mount St. Helens demonstrates continued mountain building in the volcanic Cascades.

Further east, the Columbia Plateau dominates the southeastern part of the state. Vast lava flows formed this huge basin. The Columbia and Snake rivers have cut deep trenches in the Columbia Plateau. The Palouse Hills in the southeast section of the plateau is one of the state's most important agricultural regions. In the extreme southeast corner are the relatively low-lying Blue Mountains at 6,000 feet.

Part of the Rocky Mountains crosses the northeastern corner of Washington; several peaks have elevations exceeding 7,000 feet.

Rivers and Lakes

The Columbia River, the largest river in the western United States, drains the eastern half of Washington State. The river provides vast hydroelectric power to the region. The Columbia's principal tributaries include the Snake, Spokane, Wenatchee, and Yakima rivers. Many smaller rivers flow west from the Cascade Range and the Coast Ranges. The most important of these is the Chehalis River, which rises in the Willapa Hills and flows north and west to Grays Harbor, an inlet of the Pacific Ocean. Other rivers include the Cowlitz, Nisqually, and Skagit rivers.

Puget Sound, about one-fifth the size of Lake Erie, is an inlet of the Pacific Ocean; with its numerous arms, it is the state's most significant body of water. Lake Chelan, a long, narrow glacial lake in the Cascade Range, is the largest natural lake in Washington. Dams on the Columbia River have created large artificial lakes. Among these are Franklin D. Roosevelt Lake (behind Grand Coulee Dam) and Banks Lake (behind Dry Falls Dam).

Climate

Washington's climate varies greatly from west to east. A moist and mild maritime climate predominates in the western part of the state, and a cooler dry climate prevails east of the Cascade Range. The average annual temperature ranges from 51° F on the Pacific coast to 40° F in the northeast. The recorded low and high temperatures in the state have ranged from -48° F in 1968 to 118° F in 1961.

A wet, marine West Coast climate predominates in Western Washington; it is mild for its latitude due to the presence of the warm North Pacific Current offshore and the relatively warm maritime air masses. The region has frequent cloud cover, considerable fog, and long-lasting drizzles; summer is the sunniest season.

The western side of the Olympic Peninsula receives as much as 150 inches of precipitation annually, making it the wettest area of the lower 48 states. Weeks may pass without a clear day. Portions of the Puget Sound area, on the leeward side of the Olympic Mountains, are less wet, although still humid, at 50 inches of precipitation annually.

The western slopes of the Cascade Range receive some of the heaviest annual snowfall in the country, in some places more than 200 inches. In the rain shadow east of the Cascades, the annual precipitation is only six inches. Precipitation increases eastward toward the Rocky Mountains, however.

The climate east of the Cascade Mountains has characteristics of both continental and marine climates. Summers are warmer, winters are colder, and precipitation is less than in western Washington. Extremes in both summer and winter temperatures generally occur when air from the continent influences the inland basin.

Annual precipitation ranges from seven to nine inches near the confluence of the Snake and Columbia Rivers in the Tri-Cities area to 15 to 30 inches along the eastern border. During July and August, four to eight weeks can pass with only a few scattered showers. Thunderstorms and a few damaging hailstorms are reported each summer. During the coldest months, freezing drizzle occasionally occurs, as does a Chinook wind that produces a rapid rise in temperature.

Economy

Before its settlement in the mid-19th century, the region that is now Washington State was important for its fur-trapping industry. Agriculture and lumbering gradually developed around Puget Sound and in some outlying areas. A major stimulus to the development of these embryonic economies was the construction of transcontinental and north-south railroads in the late 19th century. By the end of the century, shipping had become important. In the 20th century, the construction of dams on the Columbia River provided irrigation water for the dry farmlands of the east and furnished cheap electric power. Manufacturing began its rapid growth in the state in the World War II period, when the federal government established defense industries here.

According to the U.S. Bureau of Economic Analysis, the top 5 employment industries in Washington, Government, Health Care and Social Assistance, Retail Trade, Manufacturing, and Professional, Scientific, and Technical Services, made up more than fifty percent of the state employment (3,828,602 persons) as of 2011 (see Table 2, below). With the exception of government, all of these areas experienced slight growth over a twelve month period. Not only were these industries top employers in the state, all 5 were also in the top 10 industries contributing to Washington's gross domestic product (GDP). Washington State ranked 14th in state GDP and 11th in state GPD growth for 2011 per US BEA statistics.

Table 1. Washington Key Employment Industries, 2011

WA Industry	WA 2011 Employment	WA Gross Domestic Product (GDP)	% WA GDP
Government	625,354	$52,757,000,000	14.90%
Manufacturing	285,924	$44,135,000,000	12.40%
Real Estate and Rental and Leasing	180,007	$43,123,000,000	12.10%
Information	115,125	$31,283,000,000	8.80%
Professional, Scientific, and Technical Services	281,428	$25,490,000,000	7.20%
Retail Trade	385,483	$25,057,000,000	7.10%
Health Care and Social Assistance	389,696	$24,798,000,000	7.00%
Wholesale Trade	134,801	$19,633,000,000	5.50%
Finance and Insurance	159,338	$17,317,000,000	4.90%
Construction	192,146	$12,883,000,000	3.60%
Administrative and Waste Management Services	191,508	$10,403,000,000	2.90%
Accommodation and Food Services	245,567	$10,104,000,000	2.80%
Transportation and Warehousing	110,649	$9,724,000,000	2.70%
Other Services, Except Government	198,003	$8,023,000,000	2.30%
Agriculture, Forestry, Fishing, and Hunting	120,346	$6,393,000,000	1.80%
Management of Companies and Enterprises	35,373	$5,042,000,000	1.40%
Utilities	5,260	$3,416,000,000	1.00%
Arts, Entertainment, and Recreation	91,264	$2,700,000,000	0.80%

Table 1. Washington Key Employment Industries, 2011

WA Industry	WA 2011 Employment	WA Gross Domestic Product (GDP)	% WA GDP
Educational Services	73,244	$2,094,000,000	0.60%
Mining	8,086	$710,000,000	0.20%
Washington State	3,828,602	$355,083,000,000	100%

Source: Bureau of Economic Analysis, Regional Data, GDP & Personal Income, 2011: Total Full-time and Part-time Employment by Industry, Gross Domestic Product.

International Trade[2]

Washington has over 75 public deep-water ports, 139 airports, more than 7,000 miles of highways, and 3,600 miles of railways, making it one of the top trade hubs in the world. In 2011, Washington exports reached $64.6 billion (a 21 percent increase from the previous year). In 2010, the top export markets for Washington State were Mainland China (accounting for the largest share at more than $10 billion), followed by Canada at $7 billion. Additional top trade partners include Japan, Korea, Indonesia, Taiwan, Germany, and Ireland. Washington is the largest U.S. exporter on a per capita basis.

Leading exports included aircraft, engine, and parts, agricultural products, electronic components and parts, fur, and special industry machinery. Leading imports included crude oil and other similar products, parts for airplanes or helicopters, motor vehicles, live cattle, coffee, wood products, and televisions and other video and gaming equipment.[3]

Ports are extremely important to Washington trade. In 2011, more than $145 billion in goods moved through the state's ports (imports and exports/domestic and international). The top ports were the Ports of Seattle ($43 billion) and Tacoma (nearly $28 billion) handling the bulk of the waterborne freight.

Agriculture

As for 2011, the food and agricultural industry was a $46 billion industry in the state, making up 13 percent of the state's economy and employing approximately 160,000 people. The state leads in the nation in production of eleven crops including apples, sweet cherries, pears, raspberries, and hops, and produces over 300 crops in all. Some of the top grossing commodities include milk, wheat, potatoes, hay, cattle, cherries, nurseries, and grapes. Washington State was ranked 14th in the country in agricultural receipts per 2004 statistics (last year available before state-level statistics were suspended by the USDA Economic Research Service).

As of the 2007 Census of Agricultural, the state had over 36,000 farms (a 9 percent increase since 2002), which average 381 acres. Agriculture is concentrated in the Puget Sound area and the somewhat isolated valleys to the south, in the dry-farmed holdings of the eastern two-thirds of the state, and in the irrigated land on the upper Columbia, Snake, and lesser rivers. Crops make up about two-thirds of the yearly farm income. Wheat, grown primarily in the east, is the state's leading field crop. Fruits, nuts, and berries account for more than one-third of the value of the crops produced in the state.

Livestock products account for about one-third of annual agricultural income. Dairy farming is concentrated in the Puget Sound region and in valleys of the southwest. Cattle and sheep are raised in the drier, eastern part of the state.

The fishing industry is significant, although it is a small part of the state's economy. Ports on Puget Sound and the Pacific Ocean handle almost all landings. According to the National Marine Fisheries Service, in 2011, clam and crab each accounted for about one-quarter of the value of the catch of commercial fishery landings for Washington, followed by oyster, salmon, tuna, and sablefish. Other commercial fish products caught include hake, shrimp, halibut, mussel, and sea cucumber.[4]

Agricultural, forestry, fishing, and hunting (reported as a combined industry) made up 1.8 percent of the Washington's 2011 state gross domestic product.[5]

Forestry

Forestry is a major industry in Washington, second in the nation to Oregon. According to the Washington Timber Harvest 2011 report, about 95 percent of harvested wood is softwood, primarily Douglas fir and western hemlock. Nearly all of the harvest is in the moist valleys of the Cascade Range and to the west. More than 54 percent of the harvest becomes lumber, almost 27 percent exported as round wood, and the remainder used for pulp and plywood.[2]

Mining

Metallic mineral resources are primarily in the mountains in the northeastern part of the state. Lead, zinc, magnesium, and gold are present here. Coal deposits are in the western Cascades; sand and gravel are in many areas. The mining industry accounts for less than 1 percent of the annual gross state product in Washington (2011). Leading mineral products include coal, Portland cement, sand and gravel, and stone. Other minerals produced include diatomite, crude gypsum, lime, magnesium, olivine, and silver.

Manufacturing

Manufacturing accounts for 12.4 percent of the annual gross state product in Washington (2011), according to the U.S. Bureau of Economic Analysis. The leading manufactured products include transportation equipment, primarily aircraft and aerospace equipment; computer and electronic products (including microchips); lumber and wood products; paper; food products; industrial machinery; primary metals; printed materials; and precision instruments. Most industry is concentrated in the urbanized corridor along Puget Sound between Bellingham in the north and Olympia in the south. Seattle and Tacoma are the primary industrial centers of the state. The processing of commodities from forestry, farming, and fishing tends to be located near the sources of raw materials. The state is 2nd in manufacturing in the country.

Tourism[6]

Tourism is an important state industry. Spending had been climbing steadily but took a hit due to the national recession in 2008. Total direct travel spending last peaked in 2008 at approximately $13.3 billion. This amount fell to below $12.5 billion in 2008 and has steadily rebounded to about $13.9 billion in 2011. Travel spending showed a 5.0 percent increase from 2010-2011 (mostly due to increase in hotel costs). However, there has also been a slight increase in the employment indicating potential for real growth in the industry.

Between 2007 and 2010, a majority of visitors (66 percent) were from outside of the Washington, including 11 percent international.

The state's major attractions are both rural and scenic, including three national parks – Mount Rainier, Olympic, and North Cascades – three national recreation areas – Lake Chelan, Coulee Dam/Lake Roosevelt, and Ross Lake – two natural monuments – Mount St. Helens National Volcanic Monument and Hanford Reach National Monument - and extensive areas of national forests including Olympic National Forest and Gifford Pinchot National Forest. In addition, the state maintains a system of 110 parks developed for recreational use. Seattle is the leading urban tourist attraction; its Space Needle and monorail, built for the Century 21 Exposition, the world's fair of 1962, are still in use.

Accommodations and food services as well as arts, entertainment, and recreation made up a combined 3.5 percent of the state's gross domestic product in 2011.

Transportation

Washington has a network of about 87,500 miles of federal, state, and local roads. This figure includes 764 miles of interstate highways, 7,000 miles of state routes, and 40,000 miles of county roads that cross the state from north to south and from east to west. The road system is densest in the heavily populated Puget Sound region. Twenty-three railroads serve Washington with over 3,215 miles of track. Washington is 20th in the nation in miles of rail.

Seattle, Tacoma, Kalama, Longview, and Bellingham are the most important of Washington's ports. Although most ports are located on Puget Sound or the Pacific coast, several are located on the upper Columbia River; oceangoing and river barges can navigate upstream by a 24-foot deep channel as far as the Tri-Cities (Kennewick, Pasco, and Richland). Ferries connect key points on Puget Sound with one another and with Victoria, British Columbia and Alaska. Washington State has the largest ferry system in the nation. A crude-oil pipeline reaches Puget Sound from Alberta; natural-gas pipelines extend from British Columbia to Spokane and from Alberta through Spokane to Oregon and California.

Washington has 135 airports according to the Washington State Department of Transportation. The Seattle-Tacoma and Spokane International airports dominate air traffic in the state. The former is also an important terminus for trans-pacific flights. The Bellingham, Grant County, William R. Fairchild, and Jefferson County airports are also international,

Transportation (which includes warehousing) made up 2.7 percent of the state's gross domestic product in 2011 according to the U.S. Bureau of Economic Analysis.

Energy

There are 96 energy producing plants in Washington that have a total installed capacity of 24,098 megawatts and produces about 904 trillion Btu of electricity each year. [7] Washington leads the nation in both installed capacity and annual production of hydroelectricity. The state produces 29 percent of the nation's net electricity but is 21st overall in energy production. The Grand Coulee, Chief Joseph, and John Day Dams are the key units in a system that includes six major dams on the Columbia River, four on the Snake River, and others on lesser rivers. The Grand Coulee is the largest hydroelectric power producer in the United States.

Hydroelectric facilities produce about three-quarters of the annual output of electricity, with conventional thermal installations, wind turbines, and one nuclear power station producing the rest. The state ranks sixth in the Nation for wind energy generation. The State of Washington's Energy Independence Act requires large electric utilities to obtain 15 percent of their electricity from new renewable energy resources by 2020.[8]

Given its ability to produce large amounts of energy, often in excess of need, the state exports some electricity during various times of the year.

Government[9, 10]

A Constitution adopted in 1889 and amended since then governs Washington State. The Constitution prevents a strong centralized state government. There are six statewide elected positions besides the governor that administer state agencies. Additionally, several state agencies are run by appointed commissions instead of reporting to the governor. Local governments provide basic services within counties and incorporated cities and towns, with special purpose districts allowed to provide services outside of cities and towns when the county was unable to do so.

The home-rule philosophy of government in Washington State focuses on people maintaining control of government services and actions at the lowest local level. This fosters a multitude of government organizations and results in more collegial intergovernmental interactions rather than the state directing or managing governmental activities.

Washington has 39 counties, most of which are governed by popularly elected three-member Boards of Commissioners. Other elected county officials included the Assessor, Auditor, Treasurer, Coroner, Clerk, Sheriff, and Prosecuting Attorney. Larger counties, including King, Pierce, and Snohomish Counties, have an elected County Executive and a larger elected County Council. Most of the state's 268 towns and cities have a mayor-council form of government. Some cities have a city manager-council form of government, with an elected council that hires a city manager or administrator to run day-to-day operations.

The state has a bicameral Legislature, with popularly elected Senate and House of Representatives. The 49 members of the Senate serve four-year terms, and the 98 members of the House of Representatives serve two-year terms. Two Representatives and one Senator represent each of the state's 49 legislative districts.

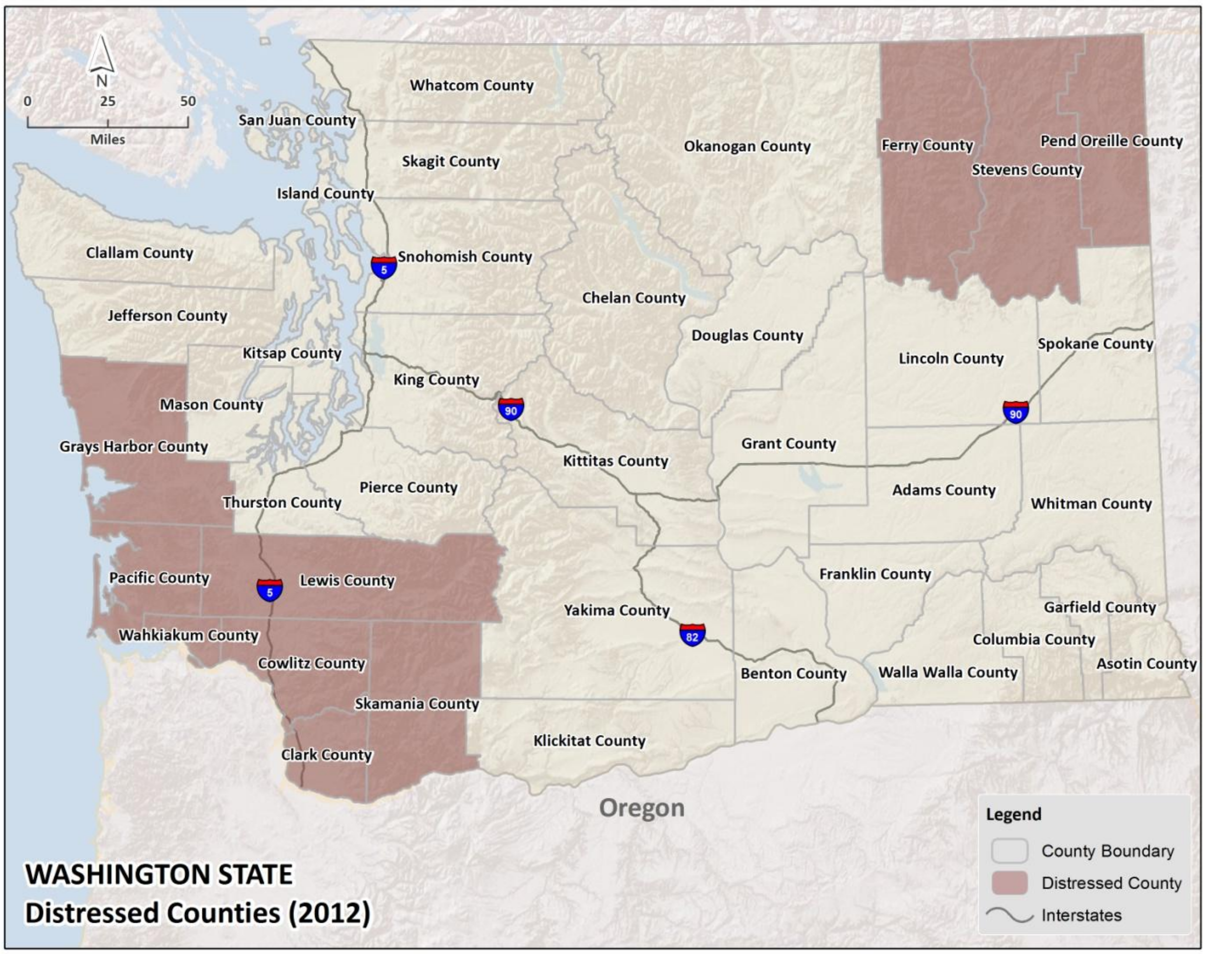
Washington's Supreme Court has a chief justice and eight associate justices. The intermediate appellate court is the 22-member Court of Appeals, and the major trial courts are the Superior Courts of the counties, which have 147 judges. Voters elect the judges of all these courts on nonpartisan ballots.

Government jobs made of 14.9 percent of the state's gross domestic product in 2011 according to the U.S. Bureau of Economic Analysis.

Unemployment Rates and Distressed Areas in Washington[11]

Figure 1 below identifies all counties with a three-year average (January 2009 – December 2011) unemployment rate equal to or greater than 120 percent of the statewide unemployment rate. For the period from January 2009 to December 2011, Washington had a three year average of 9.5 percent. A distressed county indicator would be a value of 11.4 percent or greater. As of 2012, ten counties were identified as distressed. This is a decreased of eight counties from the 2009 data, though the statewide unemployment rate has also increased dramatically (up from 4.9 percent).

Figure 2. Washington State Distressed Counties (January 2009 - December 2012)



Source: [Washington State Employment Security Department](#)[12]

State Demographic Profile

Approximately half of Washington's total population lives in the Seattle metropolitan area (Seattle, King County, Snohomish County, and Pierce County) located along the Puget Sound. This area is the center of transportation, business, and industry and is the fastest growing region in the state.

State of Washington has a population of over 6.8 million, which is expected to continue to increase in the coming decades. Understanding population is critical in order to understand where vulnerabilities are and how to best mitigate those vulnerabilities. It is also helpful to understand populations in order to know how to stage response equipment and where recovery efforts may need to be concentrated.

Since 2000, the population in Washington has become more racially and ethnically diverse. Minority residents primarily live in metropolitan counties, such as King, Pierce, Snohomish, and Yakima counties. The population is also growing older each year, and the elderly population in the state continues to rise. The counties with largest elderly populations, proportional to county size, include Jefferson, Wahkiakum, Pacific, Clallam, and San Juan counties.[13]

Population

As of April 1, 2012, the population of Washington was estimated at 6,817,770. This is an increase of nearly 50,000 persons from the previous year. The state's population grew 15.7 percent from 2000. The population is projected to rise another 9 percent by 2020 and then increase slightly over the 30-year forecast (projected to over 8 million by 2040) according to the State Office of Financial Management Forecasting Division. Washington State is the 13th most populous state in the country.

According to the April 1, 2012 estimates by the State Office of Financial Management, the 10 largest cities in the state (2012 estimates) and their growth since the 2000 Census are shown in Table 1 below:

Table 2. Washington State's Largest Cities

	City	2000 Population	2012 Population	Change 2000-2012
1.	Seattle	563,376	616,500	9.4%
2.	Spokane	195,629	210,000	7.4%
3.	Tacoma	193,556	199,600	3.1%
4.	Vancouver	143,560	163,200	13.7%
5.	Bellevue	109,827	124,600	13.5%
6.	Kent	79,524	119,000	49.6%
7.	Everett	91,488	103,300	12.9%
8.	Renton	50,052	93,910	87.6%
9.	Yakima	71,845	91,930	28.0%
10.	Spokane Valley*	82,985 (2003 population)	90,550	9.1%

* Incorporated in 2003. Percent change value represents 2003-2012 population.

Figure 3 below shows the actual population numbers of counties throughout the state. Table 3, below, shows the population growth of the state and counties from 2000 to 2012 as well as the projected rate of growth through the year 2025. Lastly, Figure 4 below shows the population throughout the state.

Franklin County was the fastest growing county from 2000 to 2012, and it is expected to remain the fastest growing county through the year 2025. Adams, Benton, Clark, Douglas, Franklin, Grant, Kittitas, Mason, Snohomish, Thurston, and Whatcom counties also had populations that grew faster than the state as a whole. Conversely, Garfield County had the greatest population loss during the same period, and it is projected to see additional loss through the year 2025. Pacific County also experienced a decline in population from 2000 to 2012.

Figure 3. 2010 Population by County

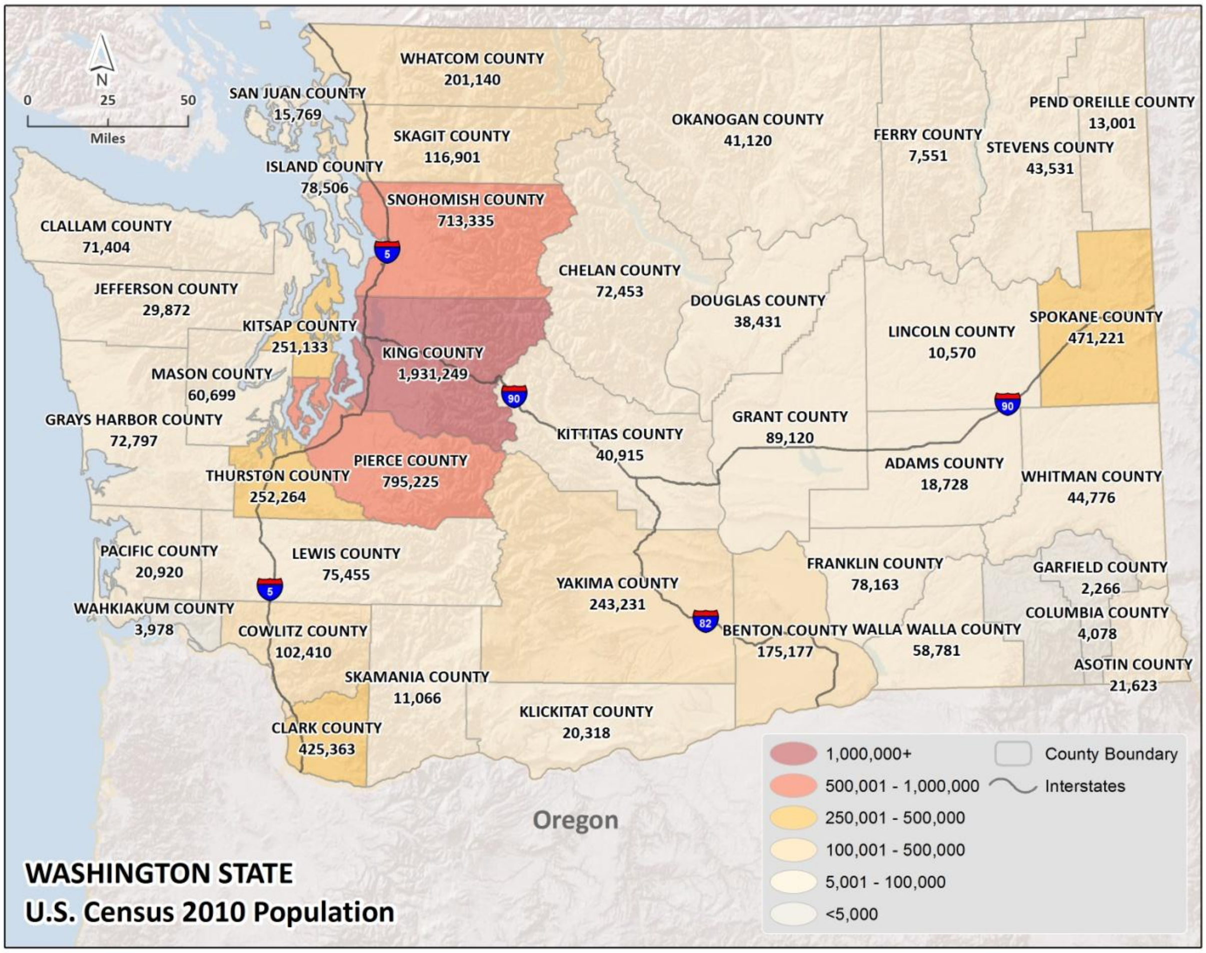


Table 3. Population Growth

	2000 Population	2010 Population	% Change '00 to '10	Est. 2012 Population	% Change '00 to '12	2025 Pop. Projection	Est. % Change '12 to '25
Adams	16,428	18,728	14.0%	19,050	16.0%	22,964	20.5%
Asotin	20,551	21,623	5.2%	21,700	5.6%	22,196	2.3%
Benton	142,475	175,177	23.0%	180,000	26.3%	210,803	17.1%
Chelan	66,616	72,453	8.8%	73,200	9.9%	81,885	11.9%
Clallam	64,179	71,404	11.3%	72,000	12.2%	75,022	4.2%
Clark	345,238	425,363	23.2%	431,250	24.9%	508,124	17.8%
Columbia	4,064	4,078	0.3%	4,100	0.9%	3,968	-3.2%
Cowlitz	92,948	102,410	10.2%	103,050	10.9%	111,706	8.4%
Douglas	32,603	38,431	17.9%	38,900	19.3%	46,662	20.0%
Ferry	7,260	7,551	4.0%	7,650	5.4%	7,751	1.3%
Franklin	49,347	78,163	58.4%	82,500	67.2%	115,142	39.6%
Garfield	2,397	2,266	-5.5%	2,250	-6.1%	2,210	-1.8%
Grant	74,698	89,120	19.3%	91,000	21.8%	112,525	23.7%
Grays Harbor	67,194	72,797	8.3%	73,150	8.9%	75,529	3.3%
Island	71,558	78,506	9.7%	79,350	10.9%	85,073	7.2%
Jefferson	26,299	29,872	13.6%	30,175	14.7%	33,678	11.6%
King	1,737,046	1,931,249	11.2%	1,957,000	12.7%	2,196,202	12.2%
Kitsap	231,969	251,133	8.3%	254,500	9.7%	289,265	13.7%
Kittitas	33,362	40,915	22.6%	41,500	24.4%	47,949	15.5%
Klickitat	19,161	20,318	6.0%	20,600	7.5%	21,225	3.0%
Lewis	68,600	75,455	10.0%	76,300	11.2%	82,924	8.7%
Lincoln	10,184	10,570	3.8%	10,675	4.8%	10,800	1.2%
Mason	49,405	60,699	22.9%	61,450	24.4%	71,929	17.1%
Okanogan	39,564	41,120	3.9%	41,425	4.7%	43,978	6.2%
Pacific	20,984	20,920	-0.3%	20,970	-0.1%	21,261	1.4%
Pend Oreille	11,732	13,001	10.8%	13,100	11.7%	13,977	6.7%
Pierce	700,818	795,225	13.5%	808,200	15.3%	923,912	14.3%
San Juan	14,077	15,769	12.0%	15,925	13.1%	16,606	4.3%
Skagit	102,979	116,901	13.5%	117,950	14.5%	136,410	15.7%
Skamania	9,872	11,066	12.1%	11,275	14.2%	12,014	6.6%
Snohomish	606,024	713,335	17.7%	722,900	19.3%	857,939	18.7%
Spokane	417,939	471,221	12.8%	475,600	13.8%	537,428	13.0%
Stevens	40,066	43,531	8.7%	43,700	9.1%	46,447	6.3%
Thurston	207,355	252,264	21.7%	256,800	23.8%	307,930	19.9%
Wahkiakum	3,824	3,978	4.0%	4,025	5.3%	3,830	-4.8%
Walla Walla	55,180	58,781	6.5%	59,100	7.1%	63,368	7.2%
Whatcom	166,826	201,140	20.6%	203,500	22.0%	241,138	18.5%
Whitman	40,740	44,776	9.9%	45,950	12.8%	49,346	7.4%
Yakima	222,581	243,231	9.3%	246,000	10.5%	282,057	14.7%
Washington	5,894,143	6,724,540	14.1%	6,817,770	15.7%	7,793,173	14.3%

Table 3. Population Growth

	2000 Population	2010 Population	% Change ’00 to ‘10	Est. 2012 Population	% Change ‘00 to ‘12	2025 Pop. Projection	Est. % Change ’12 to ‘25
State							

Source: Population and Components of Population Change by County: April 1, 200 to April 1, 2010, State of Washington Office of Financial Management, Forecasting Division, September, 2013; Population and Components of Population Change by County: April 1, 2010 to April 1, 2012, State of Washington Office of Financial Management, Forecasting Division, September, 2013;Washington State County Growth Management Population Projections: 2010 to 2040, Medium Series Projections, State of Washington Office of Financial Management, Forecasting Division, August 2012.

Figure 4. Population Change by County (2000 to 2010)

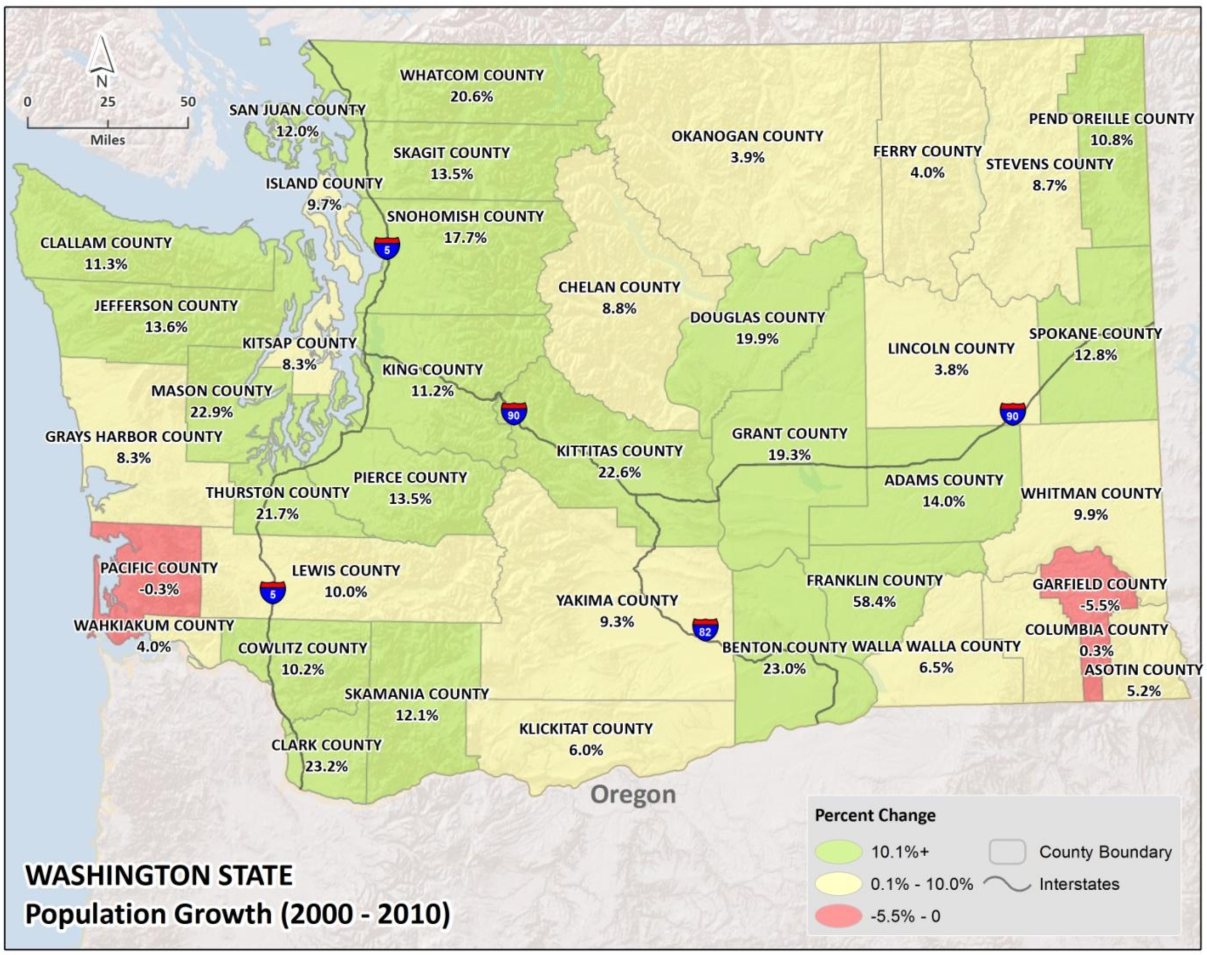


Table 4 and Figure 5, below, shows the urban and rural population distribution the counties, state, and nation. As a whole, over three-fourths of the state's population lives in densely settled urbanized areas. The most heavily urbanized counties are King, Pierce, Asotin, Benton, and Snohomish counties while the rural counties are Ferry, Garfield, Lincoln, San Juan, Skamania, and Wahkiakum. It should be noted that some of the aforementioned counties, such as Asotin, are not urban in nature but do have a majority of the its population living in urbanized areas. The current growth pattern, both urban and rural, affects how agencies prepare for emergencies as changes in the population and development can increase the risks associated with certain hazards.

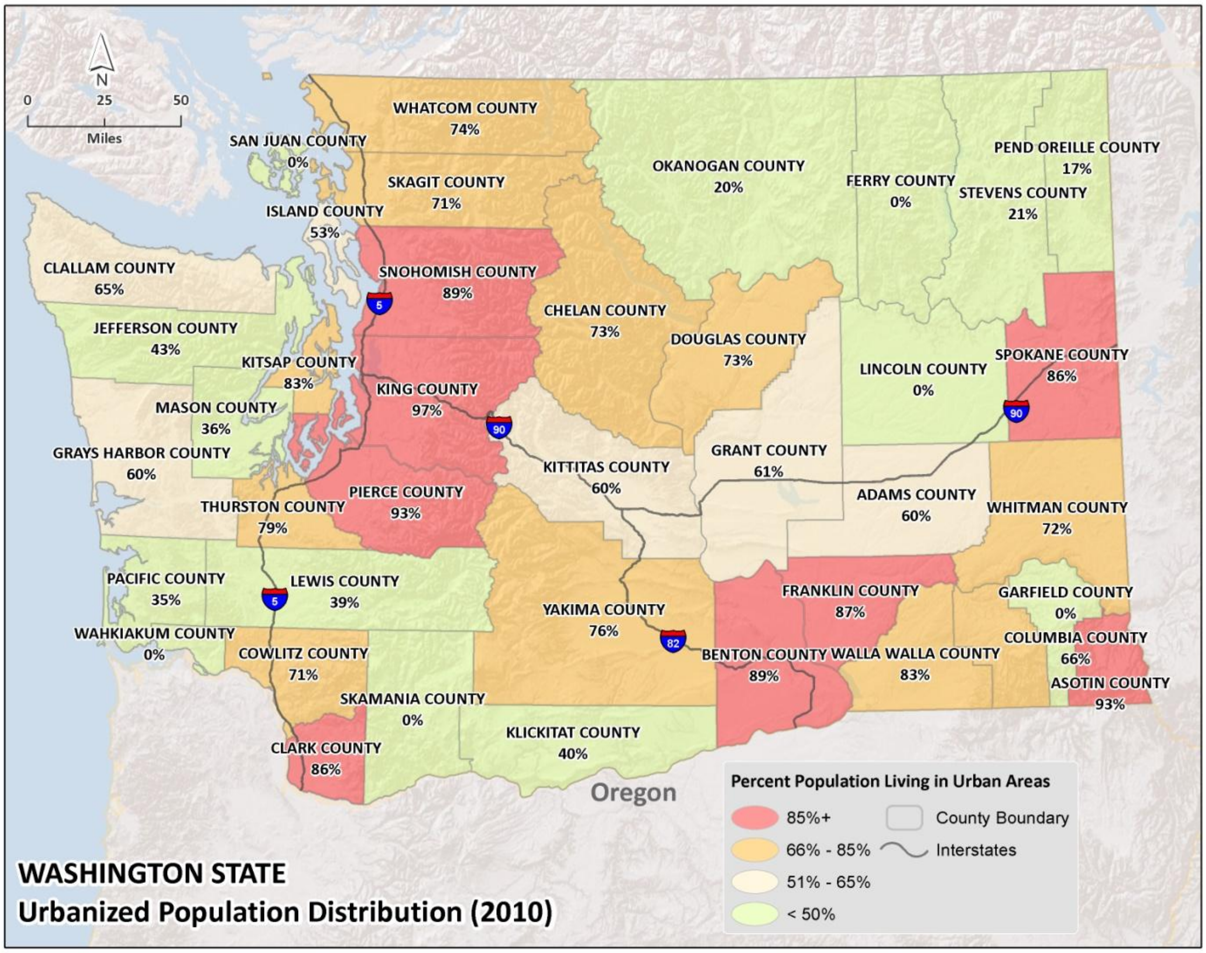
Table 4. Urban/Rural Populations, 2010

	Urban	Rural
Adams	11,207	7,521
Asotin	20,184	1,439
Benton	156,659	18,518
Chelan	52,728	19,725
Clallam	46,089	25,315
Clark	366,797	58,566
Columbia	2,681	1,397
Cowlitz	73,068	29,342
Douglas	28,210	10,221
Ferry	0	7,551
Franklin	67,741	10,422
Garfield	0	2,266
Grant	54,587	34,533
Grays Harbor	43,596	29,201
Island	41,690	36,816
Jefferson	12,705	17,167
King	1,869,311	61,938
Kitsap	209,089	42,044
Kittitas	24,526	16,389
Klickitat	8,084	12,234
Lewis	29,688	45,767
Lincoln	0	10,570
Mason	22,036	38,663

Table 4. Urban/Rural Populations, 2010

	Urban	Rural
Okanogan	8,229	32,891
Pacific	7,370	13,550
Pend Oreille	2,196	10,805
Pierce	742,814	52,411
San Juan	0	15,769
Skagit	82,975	33,926
Skamania	0	11,066
Snohomish	636,156	77,179
Spokane	406,797	64,424
Stevens	9,052	34,479
Thurston	199,317	52,947
Wahkiakum	0	3,978
Walla Walla	48,715	10,066
Whatcom	149,098	52,042
Whitman	32,449	12,327
Yakima	186,025	57,206
Washington State	5,651,869	1,072,671
Percentage	84.0%	16.0%
United States	80.7%	19.3%
Source: U.S. Census Bureau, 2010 Census: Urban and Rural Classification.		

Figure 5. Percentage of Population Living in Urban Areas by County (2010)



The ability to prepare for and recover from a disaster varies among population groups. Research on various population groups and disasters found that it took some populations longer to recover from a disaster for a variety of reasons. These population groups include minorities, people with language barriers, the disabled, senior citizens, and those with low income.

Ethnic Groups

People from non-white population groups generally experience longer recoveries due to lower incomes, savings, and insurance; their difficulty accessing insurance; and their using aid and relief organizations differently than was anticipated. Language and cultural differences can pose difficulties in some populations' understanding and implementing preparedness and mitigation actions as well as accessing and using available disaster relief.

Table 5 and Figure 6, below, show state and national figures for the race and ethnicity. Adams, Benton, Chelan, Douglas, Franklin, Grant, Okanogan, Skagit, Walla Walla County, and Yakima counties have significant Hispanic/Latino populations. Additionally, King County has a significant Asian/Pacific Islands population while Ferry County and Okanogan County have significant Native American populations.

Table 5. Population by Ethnic Group

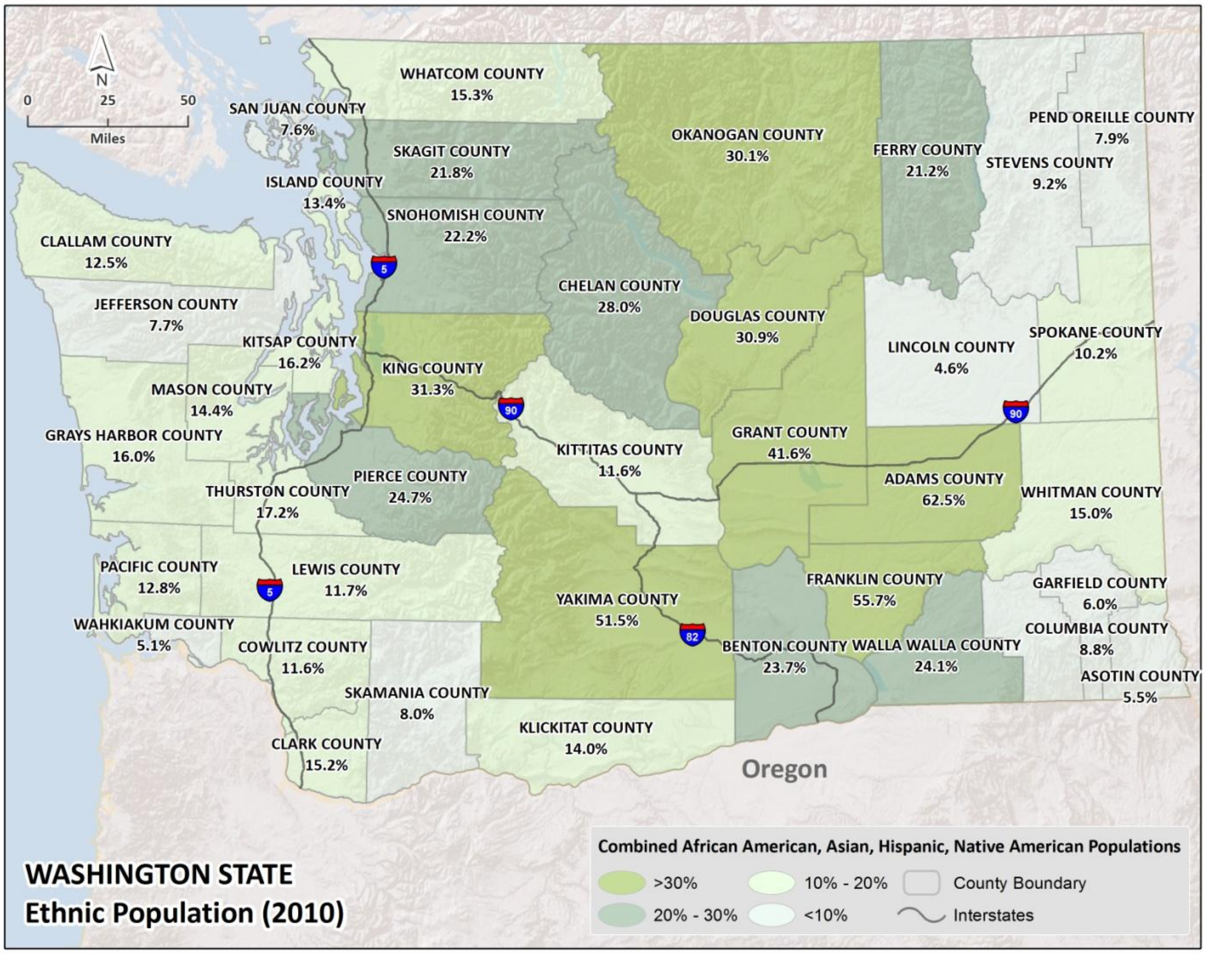
	Hispanic		Asian/Pacific Islander		African American		Native American		% Ethnic Population
	2000	2010	2000	2010	2000	2010	2000	2010	Total (2010)
Adams	47.1%	59.3%	0.6%	0.7%	0.3%	0.6%	0.7%	1.9%	62.5%
Asotin	2.0%	3.0%	0.5%	0.7%	0.2%	0.4%	1.3%	1.4%	5.5%
Benton	12.5%	18.7%	2.3%	2.8%	0.9%	1.3%	0.8%	0.9%	23.7%
Chelan	19.3%	25.8%	0.8%	0.9%	0.3%	0.3%	1.0%	1.0%	28.0%
Clallam	3.4%	5.1%	1.3%	1.5%	0.8%	0.8%	5.1%	5.1%	12.5%
Clark	4.7%	7.6%	3.6%	4.7%	1.7%	2.0%	0.8%	0.9%	15.2%
Columbia	6.3%	6.2%	0.4%	0.9%	0.2%	0.3%	1.0%	1.4%	8.8%
Cowlitz	4.6%	7.8%	1.4%	1.7%	0.5%	0.6%	1.5%	1.5%	11.6%
Douglas	19.7%	28.7%	0.6%	0.8%	0.3%	0.3%	1.1%	1.1%	30.9%
Ferry	2.8%	3.4%	0.4%	0.8%	0.2%	0.3%	18.3%	16.7%	21.2%
Franklin	46.7%	51.2%	1.7%	1.9%	2.5%	1.9%	0.7%	0.7%	55.7%
Garfield	2.0%	4.0%	0.7%	1.7%	0.0%	0.0%	0.4%	0.3%	6.0%
Grant	30.1%	38.3%	1.0%	1.0%	1.0%	1.1%	1.2%	1.2%	41.6%
Grays Harbor	4.8%	8.6%	1.3%	1.7%	0.3%	1.1%	4.7%	4.6%	16.0%
Island	4.0%	5.5%	4.6%	4.9%	2.4%	2.2%	1.0%	0.8%	13.4%
Jefferson	2.1%	2.8%	1.3%	1.8%	0.4%	0.8%	2.3%	2.3%	7.7%
King	5.5%	8.9%	11.3%	15.4%	5.4%	6.2%	0.9%	0.8%	31.3%
Kitsap	4.1%	6.2%	5.2%	5.8%	2.9%	2.6%	1.6%	1.6%	16.2%
Kittitas	5.0%	7.6%	2.3%	2.1%	0.7%	0.9%	0.9%	1.0%	11.6%
Klickitat	7.8%	10.7%	0.9%	0.7%	0.3%	0.2%	3.5%	2.4%	14.0%
Lewis	5.4%	8.7%	0.9%	1.1%	0.4%	0.5%	1.2%	1.4%	11.7%
Lincoln	1.9%	2.3%	0.3%	0.4%	0.2%	0.3%	1.6%	1.6%	4.6%
Mason	4.8%	8.0%	1.5%	1.6%	1.2%	1.1%	3.7%	3.7%	14.4%
Okanogan	14.4%	17.6%	0.5%	0.7%	0.3%	0.4%	11.5%	11.4%	30.1%
Pacific	5.0%	8.0%	2.2%	2.1%	0.2%	0.4%	2.4%	2.3%	12.8%
Pend Oreille	2.1%	3.0%	0.8%	0.7%	0.1%	0.4%	2.9%	3.8%	7.9%
Pierce	5.5%	9.2%	5.9%	7.3%	7.0%	6.8%	1.4%	1.4%	24.7%
San Juan	2.4%	5.4%	1.0%	1.2%	0.3%	0.3%	0.8%	0.7%	7.6%
Skagit	11.2%	16.9%	1.7%	2.0%	0.4%	0.7%	1.9%	2.2%	21.8%

Table 5. Population by Ethnic Group

	Hispanic		Asian/Pacific Islander		African American		Native American		% Ethnic Population
	2000	2010	2000	2010	2000	2010	2000	2010	Total (2010)
Skamania	4.0%	5.0%	0.7%	1.0%	0.3%	0.4%	2.2%	1.6%	8.0%
Snohomish	4.7%	9.0%	6.1%	9.3%	1.7%	2.5%	1.4%	1.4%	22.2%
Spokane	2.8%	4.5%	2.1%	2.5%	1.6%	1.7%	1.4%	1.5%	10.2%
Stevens	1.8%	2.7%	0.7%	0.7%	0.3%	0.3%	5.7%	5.5%	9.2%
Thurston	4.5%	7.1%	4.9%	6.0%	2.4%	2.7%	1.5%	1.4%	17.2%
Wahkiakum	2.6%	2.7%	0.6%	0.8%	0.3%	0.3%	1.6%	1.3%	5.1%
Walla Walla	15.7%	19.7%	1.3%	1.6%	1.7%	1.8%	0.8%	1.0%	24.1%
Whatcom	5.2%	7.8%	2.9%	3.7%	0.7%	1.0%	2.8%	2.8%	15.3%
Whitman	3.0%	4.6%	5.8%	8.0%	1.5%	1.7%	0.7%	0.7%	15.0%
Yakima	35.9%	45.0%	1.1%	1.2%	1.0%	1.0%	4.5%	4.3%	51.5%
Washington State	7.5%	11.2%	5.9%	7.8%	3.2%	3.6%	0.7%	1.5%	24.1%
United States	12.5%	16.3%	3.7%	5.0%	12.3%	12.6%	0.9%	0.9%	34.8%

Source: U.S. Census Bureau, 2000 and 2010 Census: Profile of General Population and Housing Characteristics.

Figure 6. State of Washington Ethnic Population (2010)



Limited English Proficiency

Nearly twenty percent of the state's population does not speak English as its primary language at home and nearly ten percent speaks English less than very well, as shown in Table 6 and Figure 7, below.

This means that a significant segment of the population may have a language barrier that prevents them from preparing for a disaster, responding to an event, or applying for assistance after a disaster.

The Table 6 below reports information for each county during the period from 2006 to 2010.

Table 6. Primary Language Spoken at Home

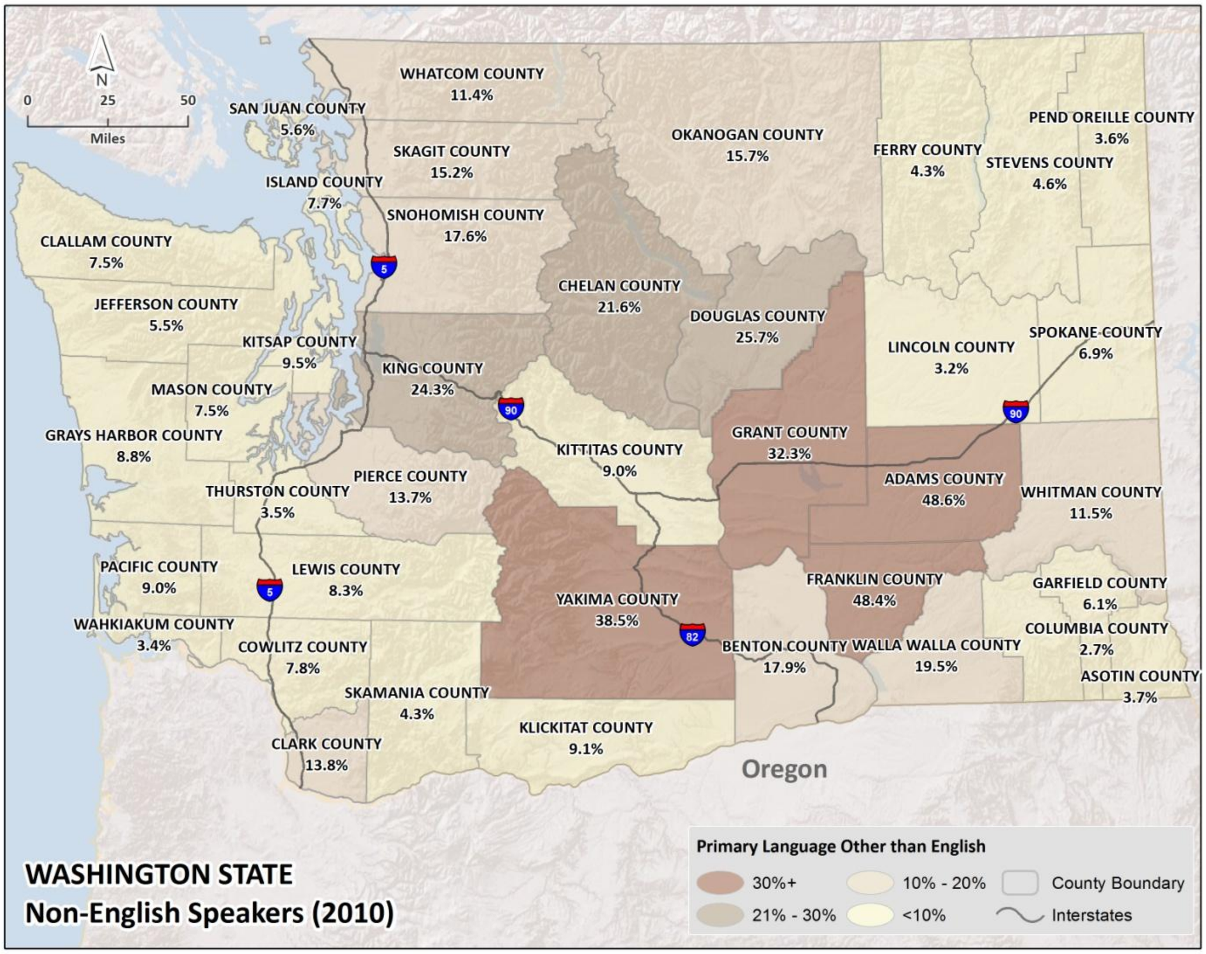
	Language Other Than English	English Less Than Very Well	Spanish	English Less Than Very Well	Other Indo-European	English Less Than Very Well	Asian-Pacific Islander	English Less Than Very Well
Adams	48.6%	25.9%	46.9%	25.1%	0.9%	0.1%	0.6%	0.5%
Asotin	3.7%	0.8%	2.0%	0.3%	1.2%	0.2%	0.5%	0.3%
Benton	17.9%	10.4%	13.3%	6.6%	2.0%	0.7%	2.2%	1.0%
Chelan	21.6%	48.4%	19.9%	9.8%	1.2%	0.3%	0.2%	0.2%
Clallam	7.5%	3.4%	3.5%	1.8%	2.3%	0.8%	1.3%	0.7%
Clark	13.8%	6.3%	4.5%	2.1%	5.6%	2.6%	3.1%	1.5%
Columbia	2.7%	0.8%	2.4%	0.8%	0.2%	0.0%	0.2%	0.0%
Cowlitz	7.8%	3.5%	5.0%	2.2%	1.3%	0.5%	1.3%	0.7%
Douglas	25.7%	12.4%	23.8%	12.2%	1.2%	0.2%	0.5%	0.1%
Ferry	4.3%	1.1%	2.0%	0.4%	1.3%	0.0%	0.7%	0.7%
Franklin	48.4%	30.2%	44.0%	27.9%	2.5%	1.3%	1.6%	1.6%
Garfield	6.1%	3.1%	4.2%	2.3%	1.1%	0.0%	0.3%	0.3%
Grant	32.3%	17.1%	29.4%	15.9%	2.0%	0.7%	0.7%	0.5%
Grays Harbor	8.8%	3.7%	6.2%	2.8%	0.9%	0.3%	1.3%	0.6%
Island	7.7%	2.1%	2.9%	0.6%	1.7%	0.2%	3.0%	1.2%
Jefferson	5.5%	1.6%	2.5%	0.6%	2.2%	0.7%	0.6%	0.2%
King	24.3%	11.0%	6.3%	3.1%	5.7%	5.1%	10.5%	5.1%
Kitsap	9.5%	3.3%	3.4%	1.3%	1.8%	0.4%	4.0%	1.6%
Kittitas	9.0%	3.3%	5.5%	2.1%	1.8%	0.3%	1.5%	0.8%
Klickitat	9.1%	3.3%	8.0%	3.1%	0.5%	0.0%	0.3%	0.2%
Lewis	8.3%	3.7%	6.2%	3.1%	1.4%	0.2%	0.5%	0.2%
Lincoln	3.2%	0.7%	2.1%	0.5%	1.0%	0.1%	0.2%	0.1%
Mason	7.5%	3.7%	5.4%	3.7%	1.0%	0.3%	1.0%	0.4%
Okanogan	15.7%	6.6%	14.0%	6.1%	1.1%	0.4%	0.4%	0.1%
Pacific	9.0%	4.6%	6.4%	3.6%	0.8%	0.1%	1.6%	0.8%
Pend Oreille	3.6%	1.0%	1.8%	0.4%	0.7%	0.1%	0.7%	0.4%
Pierce	13.7%	5.7%	5.4%	2.2%	2.7%	0.9%	5.2%	2.5%
San Juan	5.6%	2.4%	3.5%	2.0%	1.3%	0.2%	0.5%	0.2%
Skagit	15.2%	6.3%	11.5%	5.2%	2.1%	0.4%	1.4%	0.6%
Skamania	4.3%	1.1%	2.9%	0.7%	0.5%	0.1%	0.5%	0.1%

Table 6. Primary Language Spoken at Home

	Language Other Than English	English Less Than Very Well	Spanish	English Less Than Very Well	Other Indo-European	English Less Than Very Well	Asian-Pacific Islander	English Less Than Very Well
Snohomish	17.6%	7.9%	6.0%	2.9%	3.9%	1.5%	6.7%	3.2%
Spokane	6.9%	2.8%	2.3%	0.7%	2.6%	1.0%	1.6%	0.9%
Stevens	4.6%	1.1%	1.4%	0.3%	2.3%	0.7%	0.3%	0.0%
Thurston	3.5%	3.5%	3.6%	1.1%	2.0%	0.3%	4.1%	2.0%
Wahkiakum	3.4%	0.8%	1.5%	0.2%	1.4%	0.4%	0.0%	0.0%
Walla Walla	19.5%	8.7%	16.5%	8.1%	1.5%	0.1%	1.4%	0.4%
Whatcom	11.4%	4.8%	4.9%	2.0%	3.9%	1.6%	2.1%	0.9%
Whitman	11.5%	3.5%	2.1%	0.4%	2.7%	0.7%	5.0%	2.0%
Yakima	38.5%	18.8%	36.6%	18.3%	0.7%	0.2%	0.6%	0.3%
Washington State	17.5%	7.9%	7.8%	3.7%	3.6%	1.2%	5.3%	2.%
United States	20.1%	8.7%	12.5%	5.8%	3.7%	1.2%	3.1%	1.5%

Source: U.S. Census Bureau, 2006-2010 American Community Survey: Selected Social Characteristics (population over 5 years of age).

Figure 7. Non-English Speakers (2010)



Disabled People

People with disabilities often do not participate in community preparedness activities for a disaster. They have complex challenges because of hearing, sight, mobility, or mental impairments. Additionally, a significant percentage of working-age people with disabilities do not work. These factors make it difficult for the disabled to prepare in advance of a disaster. Further, disabled people face additional challenges when trying to evacuate or flee a disaster area. Understanding where these folks reside can help the state better prepare.

The State of Washington has over 780,000 non-institutionalized civilians with a disability. Just twenty percent of this population is employed (indicating that targeted preparedness and response efforts may be needed).

Table 7 and Figure 8, below, shows the state and national figures for disabled persons during the period from 2008 to 2010, as well as the counties in the state when available. About 40 percent of retirement-age people have a disability.

Table 7. Non-Institutionalized Disabled Population

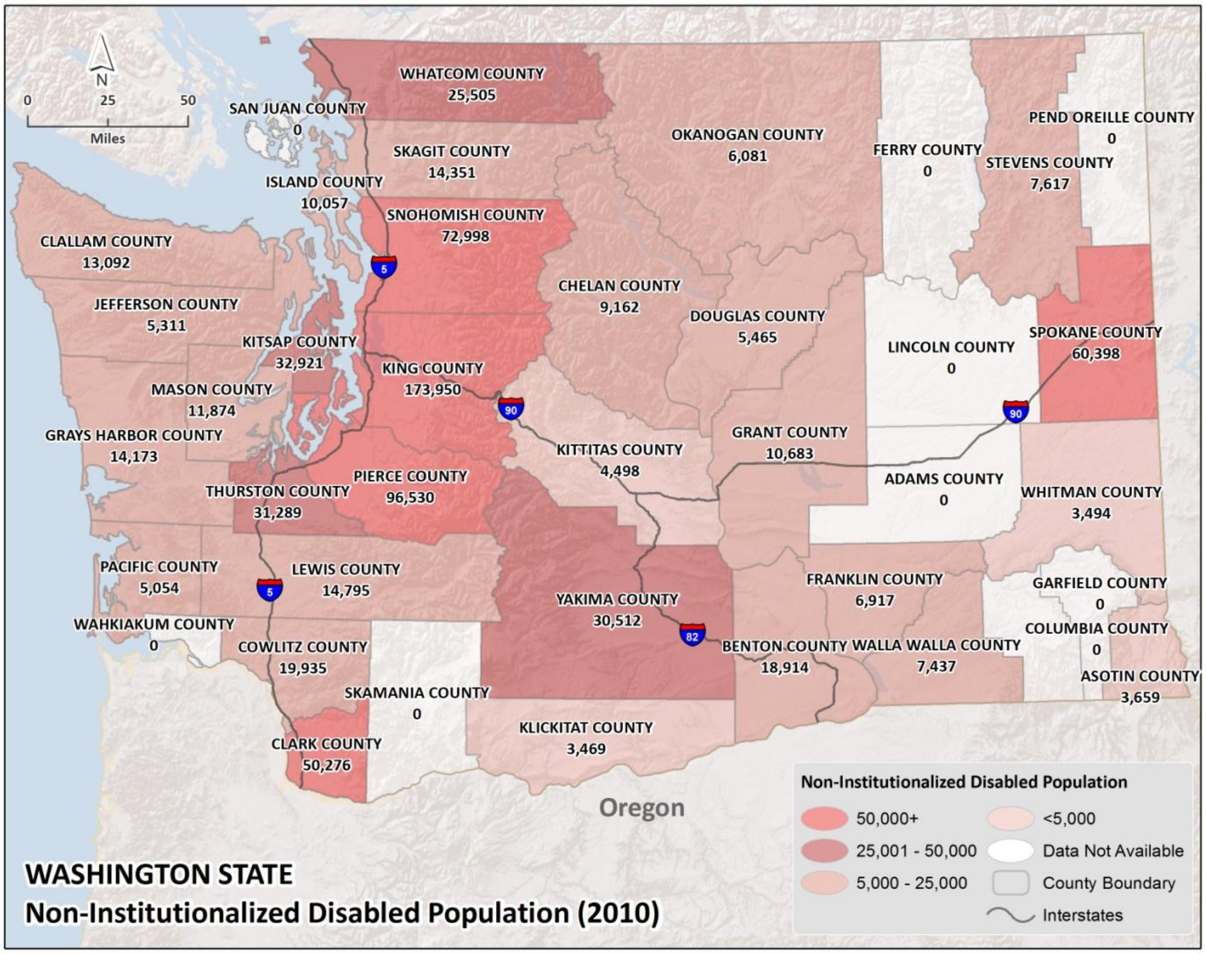
	Total disabled (non-institutionalized)	% of population	% of Population 18 to 64 years	% of Population 65 years and older	% Employed with a Disability
Adams	(X)	(X)	(X)	(X)	(X)
Asotin	3,659	17.2%	13.3%	45.0%	9.5%
Benton	18,914	11.1%	9.9%	34.8%	23.2%
Chelan	9,162	12.8%	10.6%	38.7%	21.9%
Clallam	13,092	19.10%	15.5%	38.1%	15.4%
Clark	50,276	12.0%	10.7%	37.5%	21.5%
Columbia	(X)	(X)	(X)	(X)	(X)
Cowlitz	19,935	19.6%	18.1%	45.6%	18.3%
Douglas	5,465	14.5%	13.4%	37.9%	25.9%
Ferry	(X)	(X)	(X)	(X)	(X)
Franklin	6,917	9.3%	10.0%	37.4%	20.5%
Garfield	(X)	(X)	(X)	(X)	(X)
Grant	10,683	12.3%	9.9%	50.3%	17.2%
Grays Harbor	14,173	20.3%	19.5%	42.9%	19.1%
Island	10,057	13.7%	12.2%	29.5%	26.0%
Jefferson	5,311	18.5%	13.8%	34.9%	19.9%
King	173,950	9.2%	7.2%	35.3%	22.6%
Kitsap	32,921	13.9%	12.8%	36.0%	23.9%
Kittitas	4,498	11.1%	8.7%	38.1%	18.9%
Klickitat	3,469	17.2%	15.0%	42.5%	14.0%
Lewis	14,795	20.0%	17.6%	46.1%	17.7%
Lincoln	(X)	(X)	(X)	(X)	(X)
Mason	11,874	20.2%	17.7%	44.8%	18.7%
Okanogan	6,081	15.0%	13.2%	38.3%	14.1%
Pacific	5,054	24.3%	21.8%	43.8%	16.6%
Pend Oreille	(X)	(X)	(X)	(X)	(X)

Table 7. Non-Institutionalized Disabled Population

	Total disabled (non-institutionalized)	% of population	% of Population 18 to 64 years	% of Population 65 years and older	% Employed with a Disability
Pierce	96,530	12.70%	11.4%	39.9%	21.6%
San Juan	(X)	(X)	(X)	(X)	(X)
Skagit	14,351	12.5%	9.8%	36.0%	14.9%
Skamania	(X)	(X)	(X)	(X)	(X)
Snohomish	72,998	10.5%	9.1%	37.6%	24.5%
Spokane	60,398	13.2%	11.0%	39.3%	18.4%
Stevens	7,617	17.5%	16.0%	39.1%	11.7%
Thurston	31,289	12.9%	11.2%	36.6%	23.2%
Wahkiakum	(X)	(X)	(X)	(X)	(X)
Walla Walla	7,437	13.2%	10.6%	40.2%	16.8%
Whatcom	25,505	12.9%	10.7%	35.5%	24.0%
Whitman	3,494	7.9%	5.9%	33.9%	20.1%
Yakima	30,512	12.9%	11.7%	45.0%	17.6%
Washington State	783,920	12.0%	10.2%	38.0%	21.1%
United States	36,180,124	12.0%	10.0%	37.2%	18.8%

(X) indicates that the estimate is not available.
Source: U.S. Census Bureau, 2008-2010 American Community Survey: Selected Social Characteristics, Employment Status by Disability Status.

Figure 8. Non-Institutionalized Disabled Population (2010)



Senior Citizens

Senior citizens have circumstances that warrant attention in preparedness and recovery activities; their age could lead them to have trouble after a disaster, perhaps having limited mobility to leave a disaster area, not qualifying for loans, or becoming disabled as a result of the disaster.

Table 8 and Figure 9, below, shows at least one of every five people living in Clallam, Columbia, Garfield, Jefferson, Lincoln, Pacific, San Juan, and Wahkiakum counties is age 65 or older.

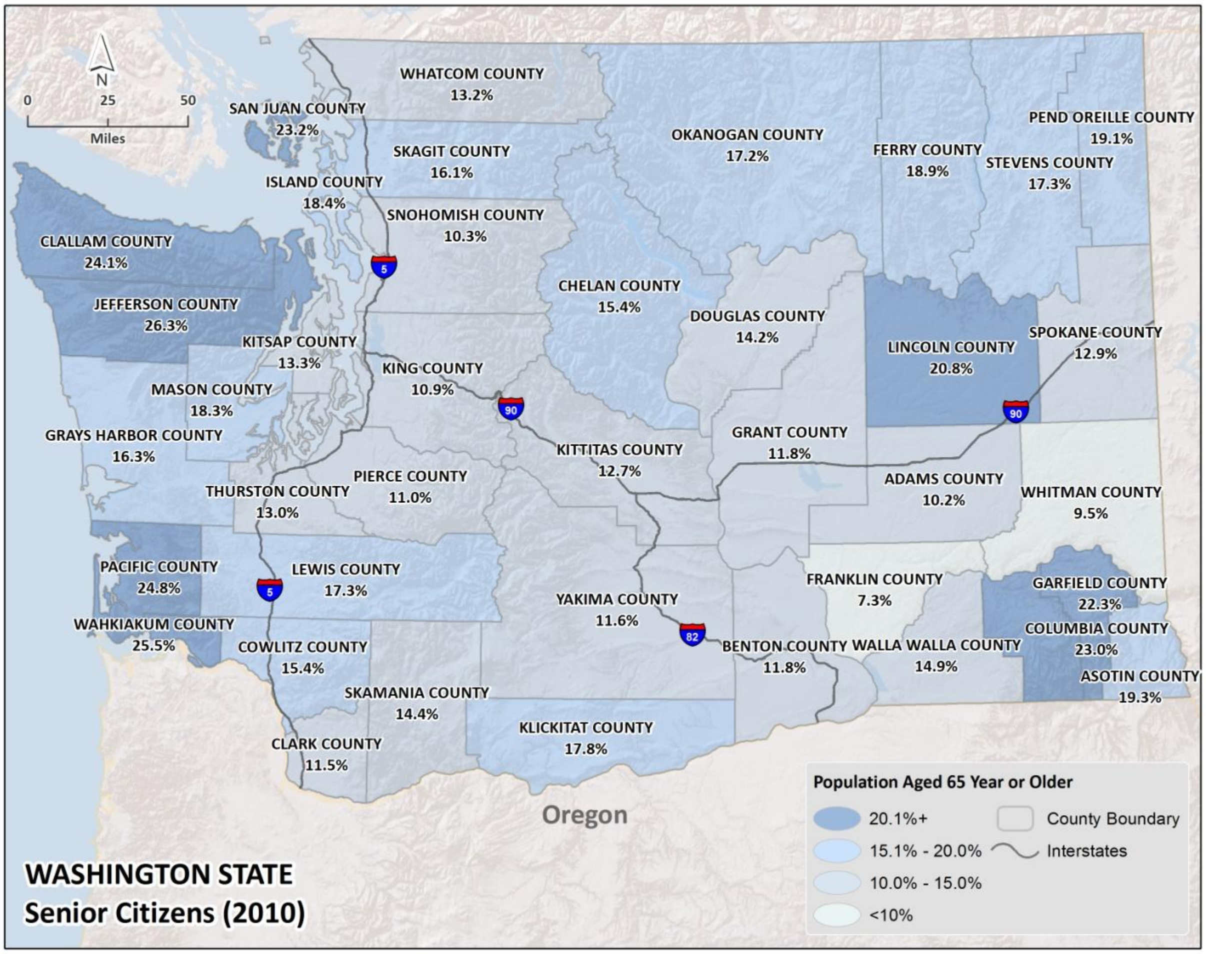
Table 8. Population Age 65 or Older

	% of Total Population
Adams	10.2%
Asotin	19.3%
Benton	11.8%
Chelan	15.4%
Clallam	24.1%
Clark	11.5%
Columbia	23.0%
Cowlitz	15.4%
Douglas	14.2%
Ferry	18.9%
Franklin	7.3%
Garfield	22.3%
Grant	11.8%
Grays Harbor	16.3%
Island	18.4%
Jefferson	26.3%
King	10.9%
Kitsap	13.3%
Kittitas	12.7%
Klickitat	17.8%
Lewis	17.3%
Lincoln	20.8%

Table 8. Population Age 65 or Older

	% of Total Population
Mason	18.3%
Okanogan	17.2%
Pacific	24.8%
Pend Oreille	19.1%
Pierce	11.0%
San Juan	23.2%
Skagit	16.1%
Skamania	14.4%
Snohomish	10.3%
Spokane	12.9%
Stevens	17.3%
Thurston	13.0%
Wahkiakum	25.5%
Walla Walla	14.9%
Whatcom	13.2%
Whitman	9.5%
Yakima	11.6%
Washington State	12.3%
United States	13.0%
Source: U.S. Census Bureau, Census 2010: Profile of General Population and Housing Characteristics.	

Figure 9. Senior Citizen Population (2010)



Poverty

The amount of money people have influences what type of housing they live in, whether they can engage in mitigation actions, and how long it takes them to recover. Income is based on a number of factors, including the individual, the economy, availability of jobs, educational opportunity, among others. Expenses can vary by location – rural places are cheaper to live but have fewer jobs, while urban areas can be costly, even for renters.

Table 9 and Figure 10, below, shows that the State of Washington had a smaller percentage of people living in poverty than the nation as a whole during the period from 2006 to 2010. The percent of people living in poverty is also shown for the counties. At least one of every five people living in Adams, Ferry, Franklin, Grant, Kittitas, Klickitat, Okanogan, Whitman, and Yakima counties is living below poverty level.

Table 9. Poverty Rates

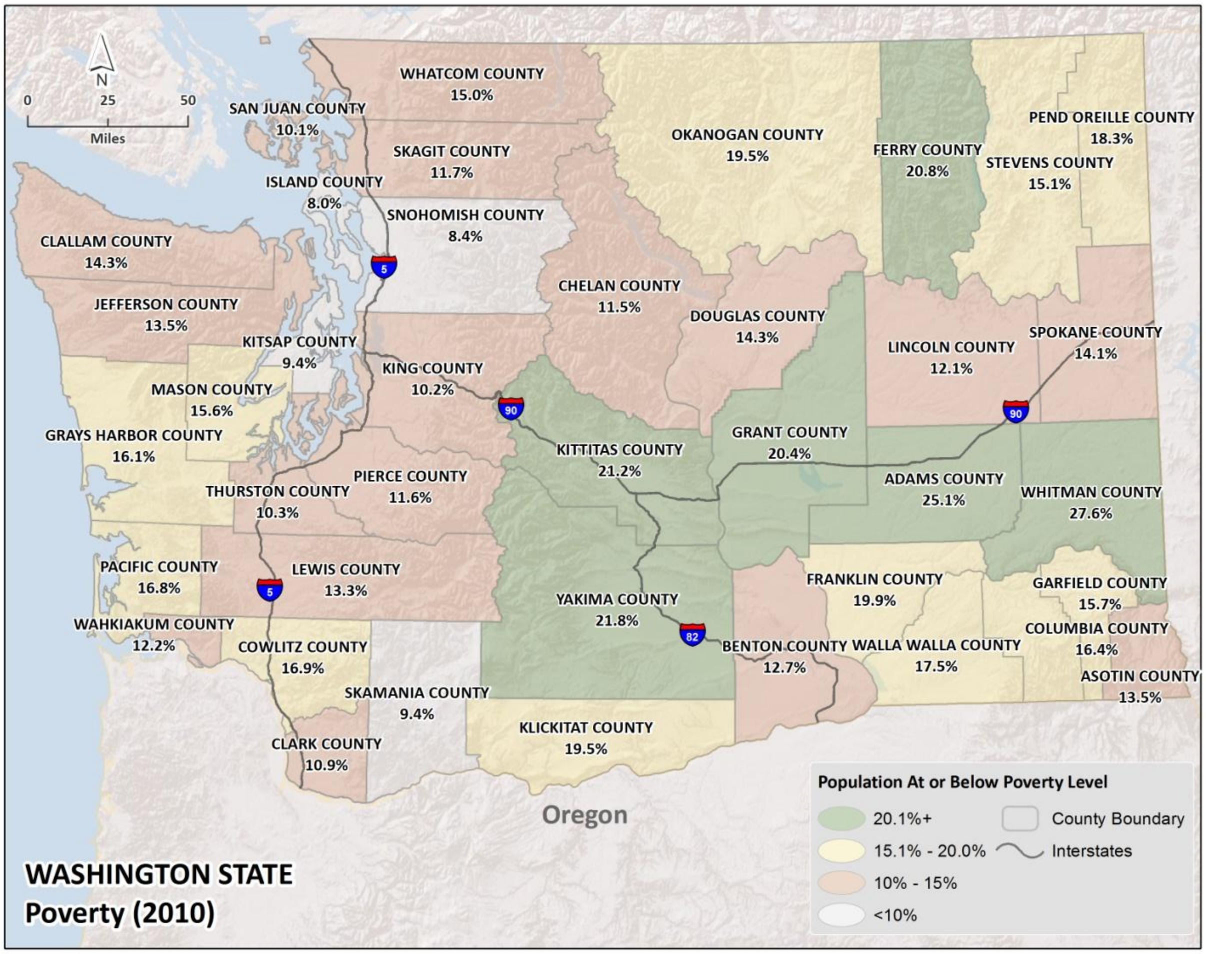
	% of Total Population	Children Under 18	Over Age 65
Adams	25.1%	36.6%	12.6%
Asotin	13.5%	21.1%	6.7%
Benton	12.7%	19.3%	6.1%
Chelan	11.5%	16.8%	9.0%
Clallam	14.3%	21.4%	6.0%
Clark	10.9%	14.9%	7.2%
Columbia	16.4%	19.7%	10.9%
Cowlitz	16.9%	23.3%	7.1%
Douglas	14.3%	22.0%	3.7%
Ferry	20.8%	24.3%	12.4%
Franklin	19.9%	25.6%	13.7%
Garfield	15.7%	22.1%	6.6%
Grant	20.4%	28.4%	7.2%
Grays Harbor	16.1%	23.1%	7.9%
Island	8.0%	12.1%	4.0%
Jefferson	13.5%	20.8%	7.4%
King	10.2%	12.5%	8.6%
Kitsap	9.4%	11.8%	5.3%
Kittitas	21.2%	19.8%	7.0%
Klickitat	19.5%	33.9%	9.4%
Lewis	13.3%	18.2%	8.6%
Lincoln	12.1%	21.5%	6.0%
Mason	15.6%	21.0%	9.0%
Okanogan	19.5%	27.3%	9.2%

Table 9. Poverty Rates

	% of Total Population	Children Under 18	Over Age 65
Pacific	16.8%	20.4%	9.9%
Pend Oreille	18.3%	25.2%	13.3%
Pierce	11.6%	15.0%	8.2%
San Juan	10.1%	13.3%	5.2%
Skagit	11.7%	16.0%	6.2%
Skamania	9.4%	10.4%	5.3%
Snohomish	8.4%	10.8%	7.3%
Spokane	14.1%	17.0%	8.5%
Stevens	15.1%	21.1%	9.3%
Thurston	10.3%	13.0%	5.9%
Wahkiakum	12.2%	14.5%	10.7%
Walla Walla	17.5%	24.6%	9.2%
Whatcom	15.0%	14.9%	7.1%
Whitman	27.6%	13.3%	5.7%
Yakima	21.8%	31.9%	11.9%
Washington State	12.1%	16.0%	7.9%
United States	13.8%	19.2%%	9.5%

Source: U.S. Census Bureau, 2006-2010 American Community Survey: Selected Economic Characteristics.

Figure 10. Poverty Levels (2010)



School Aged Children

While children overall are captured in figures elsewhere in this profile, the number of children attending school is a concern because many of the school buildings they spend considerable time in each day are older and potentially more vulnerable to the effects of disaster. Table 10 and Figure 11, below, show the population of school-age children in the state, counties, and nation during the period from 2006 to 2010; it does not show the number that are in potentially vulnerable buildings.

In 2013, the Washington Office of Superintendent of Public Instruction completed a thorough study to indicate which buildings were vulnerable to earthquake, flood, and wildfire hazards. Additional information, such as potential dollar losses, was also investigated. This information will be used to help inform decision on school retrofit and safety projects.

Table 10. School Enrollment – Kindergarten through High School

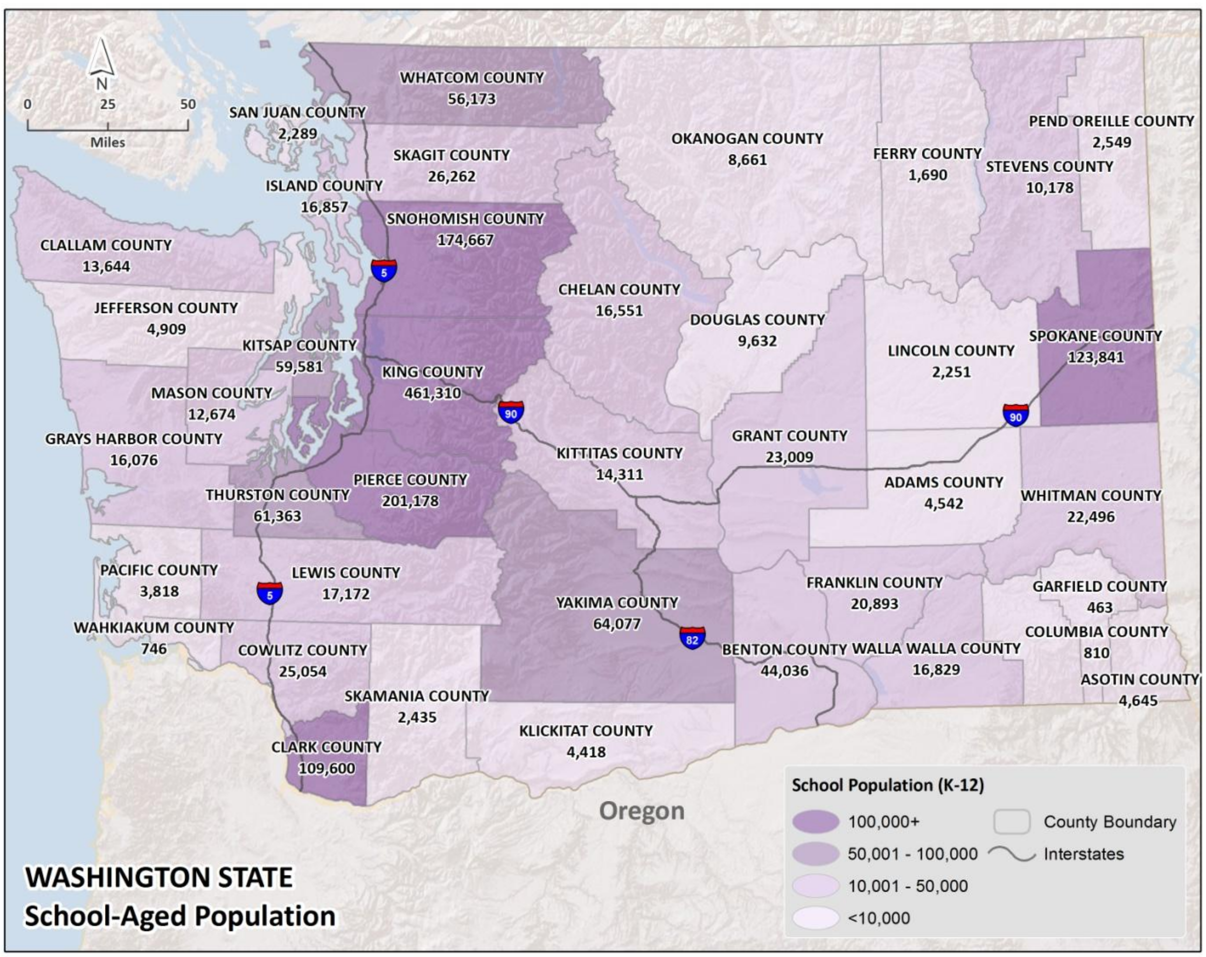
	Total*	Kindergarten	Elementary	High School
Adams	4,542	3.9%	56.1%	25.9%
Asotin	4,645	7.1%	41.9%	25.1%
Benton	44,036	5.2%	46.6%	25.0%
Chelan	16,551	5.7%	48.9%	26.7%
Clallam	13,644	4.3%	41.5%	27.3%
Clark	109,600	5.3%	45.8%	23.5%
Columbia	810	4.9%	47.4%	29.9%
Cowlitz	25,054	6.9%	42.6%	23.8%
Douglas	9,632	4.6%	47.1%	25.5%
Ferry	1,690	5.3%	45.2%	29.8%
Franklin	20,893	7.2%	49.0%	23.9%
Garfield	463	7.6%	42.5%	31.3%
Grant	23,009	5.2%	49.7%	26.8%
Grays Harbor	16,076	4.4%	43.2%	27.9%
Island	16,857	4.3%	43.9%	23.4%
Jefferson	4,909	4.4%	44.4%	26.4%
King	461,310	4.9%	37.4%	20.0%
Kitsap	59,581	4.2%	42.8%	24.4%
Kittitas	14,311	1.7%	25.5%	11.9%
Klickitat	4,418	3.9%	49.5%	23.8%
Lewis	17,172	7.4%	44.0%	27.7%
Lincoln	2,251	3.6%	49.9%	28.8%
Mason	12,674	5.6%	42.1%	25.9%
Okanogan	8,661	6.5%	45.3%	29.6%
Pacific	3,818	3.5%	41.4%	28.5%
Pend Oreille	2,549	4.4%	52.9%	30.1%
Pierce	201,178	5.3%	42.6%	23.3%
San Juan	2,289	3.8%	50.0%	27.0%
Skagit	26,262	5.8%	44.4%	25.4%
Skamania	2,435	4.5%	48.7%	27.1%
Snohomish	174,667	5.5%	42.9%	24.1%

Table 10. School Enrollment – Kindergarten through High School

	Total*	Kindergarten	Elementary	High School
Spokane	123,841	4.1%	38.4%	21.2%
Stevens	10,178	4.3%	49.9%	28.1%
Thurston	61,363	4.6%	40.9%	22.8%
Wahkiakum	746	2.4%	47.7%	33.5%
Walla Walla	16,829	3.6%	36.1%	21.1%
Whatcom	56,173	3.1%	33.8%	18.3%
Whitman	22,496	1.2%	13.1%	6.6%
Yakima	64,077	7.3%	47.9%	25.4%
Washington State	1,661,690	5.0%	40.9%	22.4%
United States	80,939,002	5.1%	40.3%	21.7%

*population 3 years and over enrolled in school.
Source: U.S. Census Bureau, 2006-2010 American Community Survey: Selected Social Characteristics.

Figure 11. State of Washington School-Aged Population (2010)



Housing

Washington's Growth Management Act encourages local jurisdictions to direct population growth into urban growth areas, where urban services support growth and higher densities. It also requires communities to incorporate mitigation by protecting critical areas and restricting development in areas such as those that are frequently flooded or subject to geologic hazards. Eliminating or limiting development in hazard-prone areas can reduce vulnerability to hazards and the potential loss of life and injuries and property damage.

Table 11 and Figure 12, below, provide a breakdown by county of various housing characteristics during the period from 2006 to 2010.

Table 11. Housing Development

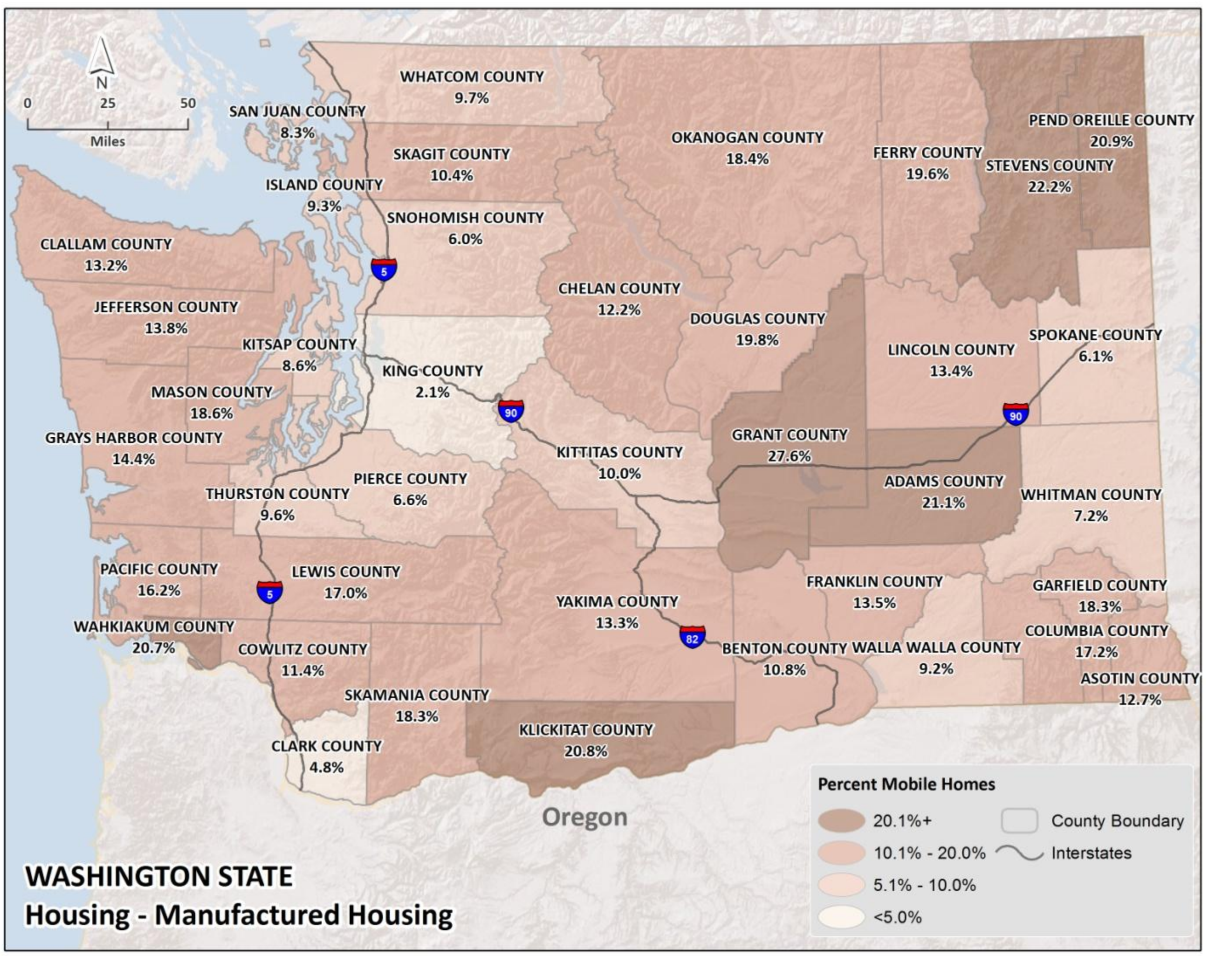
	Single-Family	Multi-Family	Mobile Homes	Other
Adams	63.2%	15.4%	21.1%	0.3%
Asotin	67.0%	18.6%	12.7%	1.7%
Benton	63.9%	25.1%	10.8%	0.2%
Chelan	67.8%	19.9%	12.2%	0.1%
Clallam	72.8%	13.5%	13.2%	0.5%
Clark	67.6%	27.4%	4.8%	0.2%
Columbia	74.6%	7.7%	17.2%	0.5%
Cowlitz	68.1%	20.3%	11.4%	0.2%
Douglas	63.9%	15.9%	19.8%	0.4%
Ferry	75.3%	4.9%	19.6%	0.2%
Franklin	66.1%	20.2%	13.5%	0.2%
Garfield	74.6%	6.3%	18.3%	0.8%
Grant	54.5%	17.7%	27.6%	0.2%
Grays Harbor	68.9%	16.4%	14.4%	0.3%
Island	77.3%	13.3%	9.3%	0.1%
Jefferson	72.1%	12.3%	13.8%	1.8%
King	55.7%	42.1%	2.1%	0.1%
Kitsap	68.4%	22.8%	8.6%	0.2%
Kittitas	64.9%	24.9%	10.0%	0.2%
Klickitat	68.0%	11.2%	20.8%	0.0%
Lewis	69.9%	12.4%	17.0%	0.7%
Lincoln	80.2%	4.9%	13.4%	1.5%
Mason	75.3%	5.6%	18.6%	0.5%
Okanogan	70.9%	10.5%	18.4%	0.2%
Pacific	72.3%	10.9%	16.2%	0.6%
Pend Oreille	72.0%	7.0%	20.9%	0.1%
Pierce	64.3%	28.9%	6.6%	0.2%
San Juan	82.4%	8.9%	8.3%	0.4%
Skagit	70.0%	19.2%	10.4%	0.4%
Skamania	75.2%	5.8%	18.3%	0.7%
Snohomish	63.9%	29.9%	6.0%	0.2%
Spokane	66.3%	27.5%	6.1%	0.1%

Table 11. Housing Development

	Single-Family	Multi-Family	Mobile Homes	Other
Stevens	71.0%	6.6%	22.2%	0.2%
Thurston	67.3%	22.8%	9.6%	0.3%
Wahkiakum	72.8%	6.3%	20.7%	0.2%
Walla Walla	66.1%	24.5%	9.2%	0.2%
Whatcom	61.1%	29.1%	9.7%	0.1%
Whitman	48.7%	44.1%	7.2%	0.0%
Yakima	65.8%	20.7%	13.3%	0.2%
Washington State	63.2%	29.3%	7.3%	0.2%
United States	61.6%	31.6%	6.7%	0.1%

Source: U.S. Census Bureau, 2006-2010 American Community Survey: Selected Housing Characteristics.

Figure 12. Mobile Homes as a Percentage of Housing Stock (2010)



The year housing was built is important for mitigation. The older a home is, the greater the risk of damage from natural disasters. Homes built after 1980 are more likely to be built to current standards for hazards such as floods, high winds, snow loads, and earthquake.

Table 12, below, shows when housing was built throughout the state during the period from 2006 to 2010. Figure 13 shows the housing stock built before 1990.

Clark, Island, Jefferson, Kitsap, Mason, San Juan, Skagit, Snohomish, Thurston, and Whatcom counties have the newest housing stock, with at least half of their housing built since 1980.

Table 12. Housing – Year Built

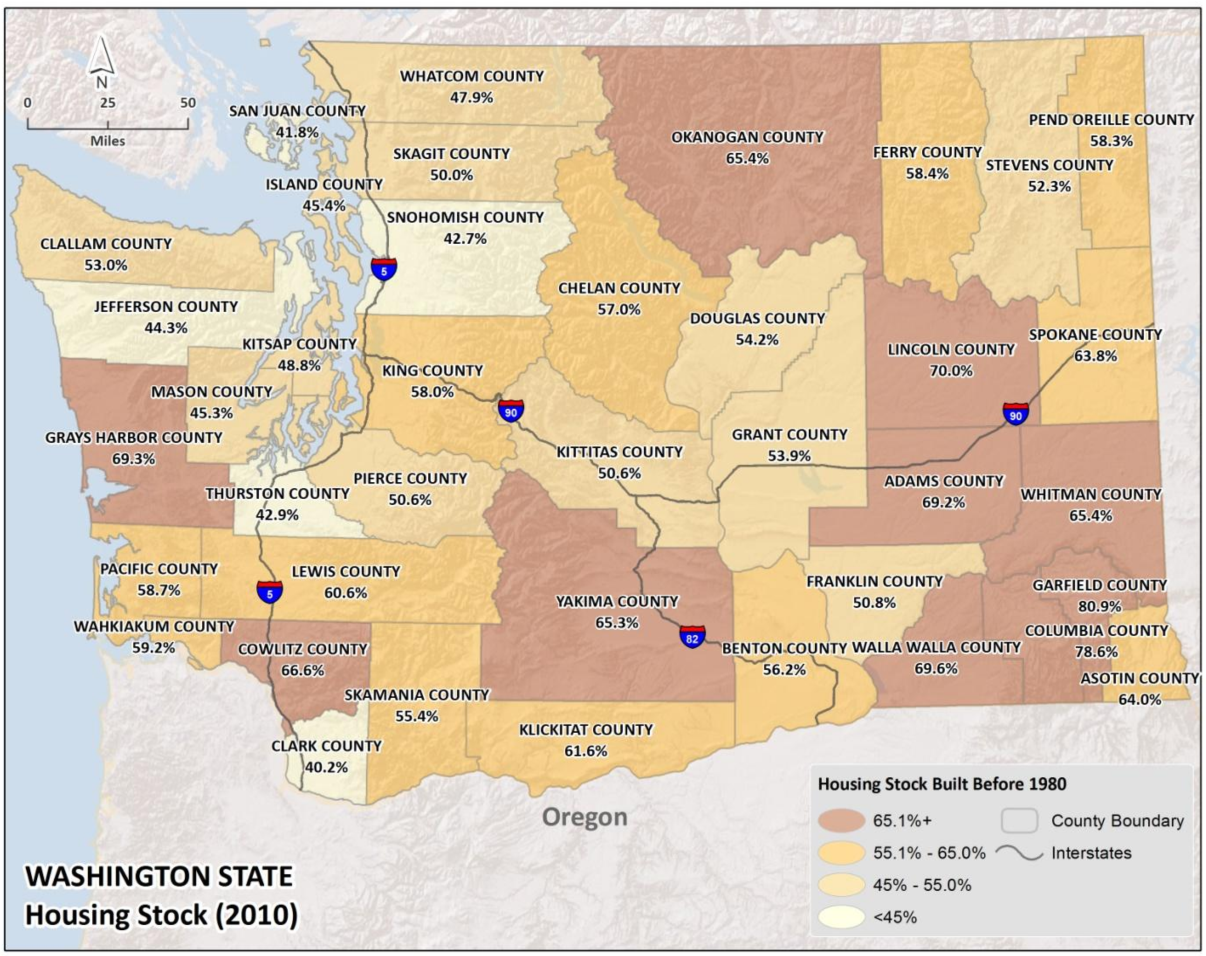
	Pre-1939 – 1959	1960 – 1979	1980 – 1999	2000 or later
Adams	31.9%	37.3%	19.5%	11.1%
Asotin	32.5%	31.5%	28.8%	7.2%
Benton	22.3%	33.9%	26.1%	17.8%
Chelan	29.6%	27.4%	33.3%	9.7%
Clallam	21.0%	32.0%	34.2%	12.8%
Clark	13.5%	26.7%	40.4%	19.4%
Columbia	51.1%	27.5%	14.1%	7.3%
Cowlitz	34.9%	31.7%	22.5%	10.8%
Douglas	22.3%	31.9%	32.8%	13.1%
Ferry	22.4%	36.0%	33.0%	8.4%
Franklin	20.8%	30.0%	19.1%	30.1%
Garfield	61.6%	19.3%	17.1%	1.9%
Grant	28.7%	25.2%	34.1%	11.9%
Grays Harbor	37.9%	31.4%	22.2%	8.6%
Island	15.8%	29.6%	38.8%	15.8%
Jefferson	15.8%	28.5%	40.3%	15.4%
King	29.4%	28.6%	29.8%	12.2%
Kitsap	20.9%	27.9%	39.5%	11.7%
Kittitas	25.8%	24.8%	32.7%	16.7%
Klickitat	35.6%	26.0%	27.8%	10.5%
Lewis	32.3%	28.3%	28.4%	11.0%
Lincoln	45.7%	24.3%	24.2%	5.9%
Mason	14.9%	30.4%	39.9%	14.7%
Okanogan	33.2%	32.2%	29.7%	4.8%
Pacific	32.0%	26.7%	35.3%	6.0%
Pend Oreille	29.6%	28.7%	33.2%	8.4%
Pierce	22.8%	27.8%	33.0%	16.3%
San Juan	14.3%	27.5%	46.3%	12.0%
Skagit	26.8%	23.2%	33.4%	16.5%
Skamania	21.2%	34.2%	34.1%	10.7%
Snohomish	15.0%	27.7%	39.7%	17.5%
Spokane	36.7%	27.1%	24.5%	11.7%
Stevens	21.4%	30.9%	36.0%	11.8%

Table 12. Housing – Year Built

	Pre-1939 – 1959	1960 – 1979	1980 – 1999	2000 or later
Thurston	13.8%	29.1%	38.8%	18.2%
Wahkiakum	31.0%	28.2%	31.4%	9.5%
Walla Walla	42.7%	26.9%	20.6%	9.8%
Whatcom	22.4%	25.5%	35.2%	17.0%
Whitman	35.0%	30.4%	20.7%	13.8%
Yakima	36.2%	29.1%	25.4%	9.3%
Washington State	25.3%	28.3%	32.3%	14.0%
United States	31.2%	27.8%	28.3%	12.8%

Source: U.S. Census Bureau, 2006-2010 American Community Survey: Selected Housing Characteristics.

Figure 13. Percentage of Housing Stock Built Before 1990 (2010)



Household Income

Median household income can be an indicator of economic stability. It compares economic areas as a whole, and generally shows the distribution of income among the population. Median household income indicates that point where half of all households have a higher income, and half have a lower income.

Table 13 and Figure 14, below, show the median county incomes compared to the state and national figures. Washington State has a value slightly above the national median household income. Figures from 2000 and 2010 were presented to show the continued rise among the top counties. Just seven counties overall had incomes higher than the national median income value. These counties typically are experiencing rises in high wage manufacturing which can be attributed to above average rates. Often lower paying trade and service jobs can contribute to low median household income values. Whitman, Okanogan, and Ferry Counties have the lowest 2010 median household income in the states ranging from $31,000 to $37,000. Those counties most aligned to the state median income value are Thurston, Pierce, Kitsap, Clark, and Skagit counties.

Table 13. Median Household Income

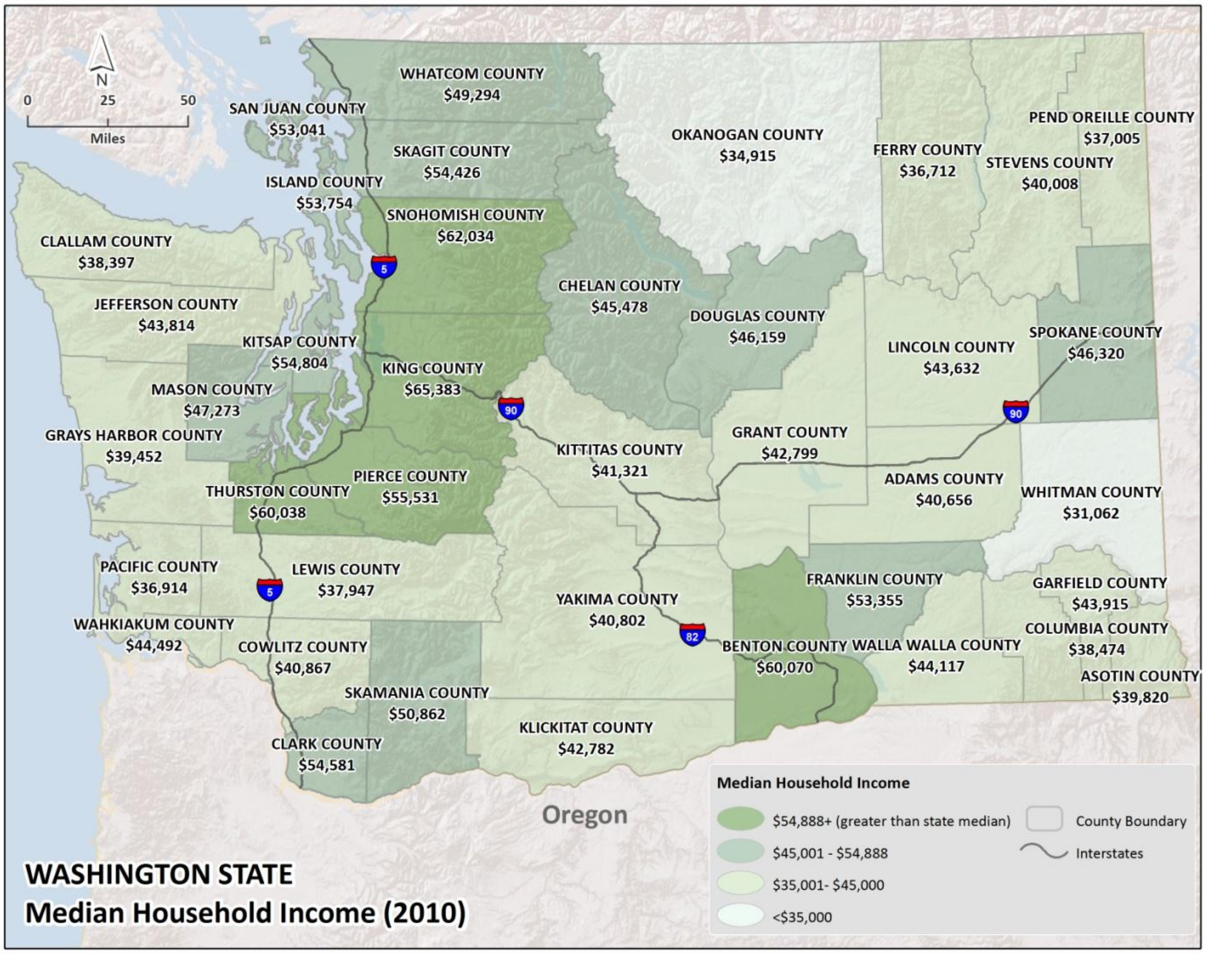
	2000	2010
Adams	$35,292	$40,656
Asotin	$32,590	$39,820
Benton	$49,389	$60,070
Chelan	$39,439	$45,478
Clallam	$30,866	$38,397
Clark	$49,320	$54,581
Columbia	$37,360	$38,474
Cowlitz	$35,246	$40,867
Douglas	$39,789	$46,159
Ferry	$31,175	$36,712
Franklin	$38,755	$53,355
Garfield	$38,507	$43,915
Grant	$37,278	$42,799
Grays Harbor	$36,410	$39,452
Island	$42,237	$53,754
Jefferson	$33,565	$43,814
King	$53,937	$65,383
Kitsap	$48,387	$54,804
Kittitas	$34,206	$41,321
Klickitat	$33,588	$42,782
Lewis	$32,968	$37,947
Lincoln	$37,188	$43,632

Table 13. Median Household Income

	2000	2010
Mason	$42,907	$47,273
Okanogan	$28,659	$34,915
Pacific	$33,263	$36,914
Pend Oreille	$33,513	$37,005
Pierce	$42,555	$55,531
San Juan	$44,568	$53,041
Skagit	$42,972	$54,426
Skamania	$40,389	$50,862
Snohomish	$50,870	$62,034
Spokane	$39,401	$46,320
Stevens	$33,370	$40,008
Thurston	$48,457	$60,038
Wahkiakum	$40,628	$44,492
Walla Walla	$34,533	$44,117
Whatcom	$37,044	$49,294
Whitman	$24,596	$31,062
Yakima	$34,630	$40,802
Washington State	$44,120	$54,888
United States	$41,186	$54,442

Source: Washington State Office of Financial Management, February 2013

Figure 14. Median Household Income by County (2010)



Average Pay

Average annual pay is another indicator of economic stability. A higher income level is associated with increased living standards and may be a sign of more productive workers.

Table 14 and Figure 15, below, show the county average annual pay in 2010. King County, Benton County, and Snohomish County have highest average annual pay in the state.

Table 14. Average Annual Pay

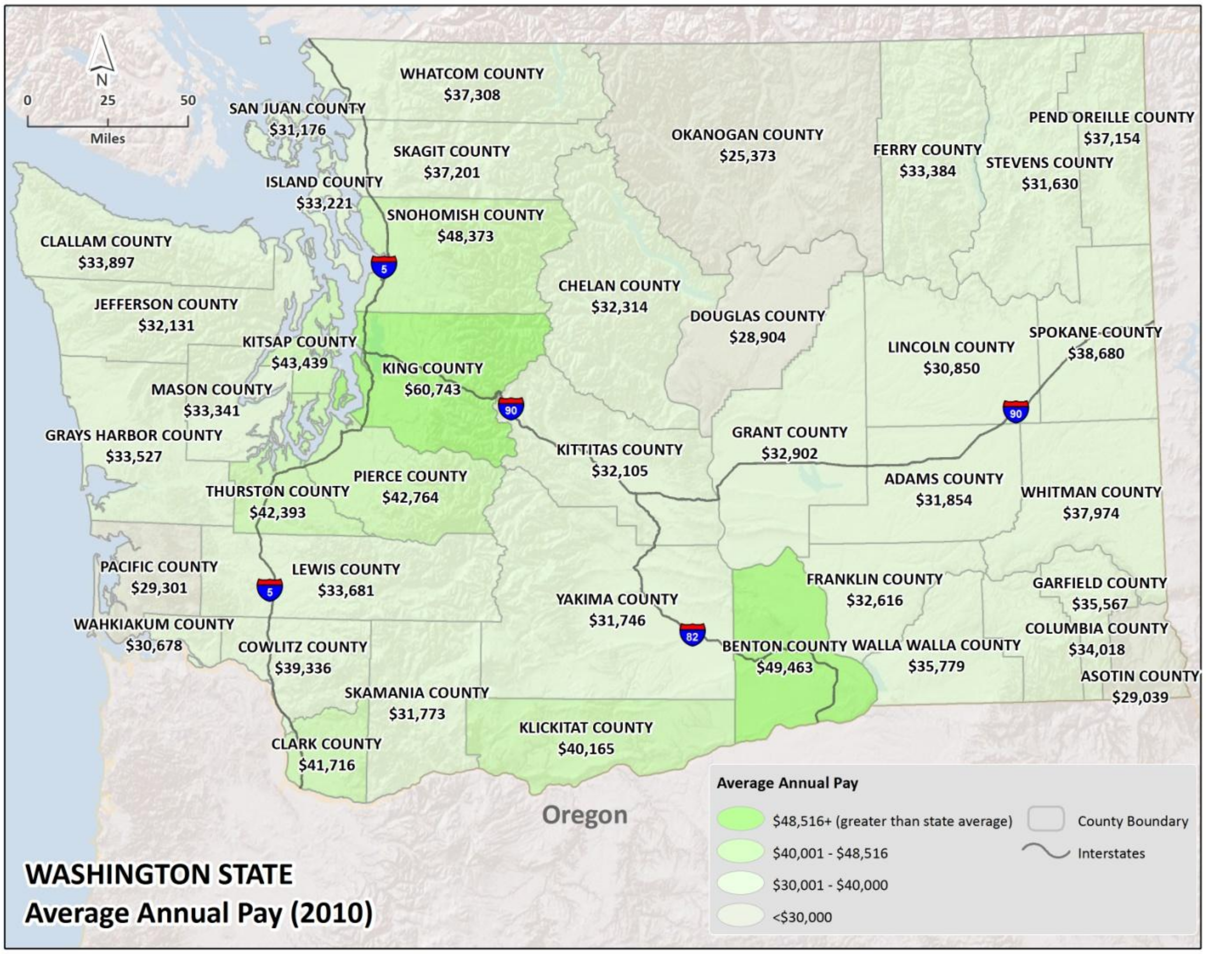
	Annual Pay
Adams	$31,854
Asotin	$29,039
Benton	$49,463
Chelan	$32,314
Clallam	$33,897
Clark	$41,716
Columbia	$34,018
Cowlitz	$39,336
Douglas	$28,904
Ferry	$33,384
Franklin	$32,616
Garfield	$35,567
Grant	$32,902
Grays Harbor	$33,527
Island	$33,221
Jefferson	$32,131
King	$60,743
Kitsap	$43,439
Kittitas	$32,105
Klickitat	$40,165
Lewis	$33,681
Lincoln	$30,850

Table 14. Average Annual Pay

	Annual Pay
Mason	$33,341
Okanogan	$25,373
Pacific	$29,301
Pend Oreille	$37,154
Pierce	$42,764
San Juan	$31,176
Skagit	$37,201
Skamania	$31,773
Snohomish	$48,373
Spokane	$38,680
Stevens	$31,630
Thurston	$42,393
Wahkiakum	$30,678
Walla Walla	$35,779
Whatcom	$37,308
Whitman	$37,974
Yakima	$31,746
Washington State	$48,516
United States	$46,751

Source: U.S. Bureau of Labor Statistics, Census of Employment and Wages: 2010.

Figure 15. Average Annual Pay (2010)



State Facilities Summary

Requirement 44 CFR §201.4(c)(2)(iii): *State Facilities Losses*. The State shall estimate the potential dollar losses to State owned or operated buildings, infrastructure, and critical facilities located in the identified hazard areas.

Data from the Washington State Office of Financial Management (OFM) was utilized for the state facility analysis. This was a 2012 dataset of state leased and owned facilities throughout the state that were self-reported by agency to the OFM. Procedures to best determine at-risk buildings were employed based on hazard and described in each hazard section. It should be noted that all buildings have some risk to earthquake. Where the earthquake occurs, its magnitude, depth, and other factors dictate the potential damage structures may incur. Several scenarios were run and are detailed in the earthquake section.

Table 15 below shows the total number of state operated facilities as well as a summary of at-risk state facilities by hazard.

Table 15. State Owned and Leased Facilities

STATEWIDE TOTAL			
	Total Number	Replacement Value	Total Square Feet
Owned	8,893	$11,858,700,000	93,425,000
Leased	1,082	$1,504,528,000	11,635,000
TOTAL	9,975	$13,363,228,000	105,060,000

Table 15. State Owned and Leased Facilities
AT-RISK BUILDINGS (Assessed for the 2013 Update)

EARTHQUAKE

	Number	At-Risk Building Replacement Value (000)	Average At-Risk Building Replacement Value (000)	At-Risk Square Feet (000)	Average At-Risk Square Feet	Building Loss (000)	Contents Loss (000)
Owned	8,893	$11,858,700,	$1,333,	93,425,	11,000	N/A	N/A
Leased	1,082	$1,504,528,	$1,391,	11,635,	11,000	N/A	N/A
TOTAL	9,975	$13,363,228,	$1,362,	105,060,	11,000	N/A	N/A

FLOOD

	Number	At-Risk Building Replacement Value (000)	Average At-Risk Building Replacement Value (000)	At-Risk Square Feet (000)	Average At-Risk Square Feet	Building Loss (000)	Contents Loss (000)
Owned	851	$1,156,065,	$1,358,	9,024,	11,000	$400,208,	$953,194,
Leased	164	$119,975,	$732,	913,	6,000	$24,844,	$79,956,
TOTAL	1,015	$1,276,040,	$1,045,	9,937,	8,500	$425,052,	$1,033,150,

WILDFIRE

	Number	At-Risk Building Replacement Value (000)	Average At-Risk Building Replacement Value (000)	At-Risk Square Feet (000)	Average At-Risk Square Feet	Building Loss (000)	Contents Loss (000)
Owned	1,585	$2,061,826,	$1,301,	16,154,	10,000	N/A	N/A
Leased	102	$39,106,	$383,	306,	3,000	N/A	N/A
TOTAL	1,687	$2,100,932,	$842,	16,460,	6,500	N/A	N/A

Table 15. State Owned and Leased Facilities
AT-RISK BUILDINGS (Not Assessed for the 2013 Update)

LANDSLIDE	Number	At-Risk Building Replacement Value	Average At-Risk Building Replacement Value	At-Risk Square Feet	Average At-Risk Square Feet	Building Loss	Contents Loss
Owned							
Leased							
TOTAL							

TSUNAMI	Number	At-Risk Building Replacement Value	Average At-Risk Building Replacement Value	At-Risk Square Feet	Average At-Risk Square Feet	Building Loss	Contents Loss
Owned							
Leased							
TOTAL							

VOLCANO	Number	At-Risk Building Replacement Value	Average At-Risk Building Replacement Value	At-Risk Square Feet	Average At-Risk Square Feet	Building Loss	Contents Loss
Owned							
Leased							
TOTAL							

Natural Hazard Profiles

Requirement §201.4(c)(2)(i) - An overview of the type and location of all natural hazards that can affect the State, including information on previous occurrences of hazard events, as well as the probability of future hazard events, using maps where appropriate;

Requirement §201.4(c)(2)(ii) - An overview and analysis of the State's vulnerability to the hazards described in this paragraph (c)(2), based on estimates provided in local risk assessments as well as the State risk assessment. The State shall describe vulnerability in terms of the jurisdictions most threatened by the identified hazards, and most vulnerable to damage and loss associated with hazard events. State owned or operated critical facilities located in the identified hazard areas shall also be addressed;

Requirement §201.4(c)(2)(iii) - An overview and analysis of potential losses to the identified vulnerable structures, based on estimates provided in local risk assessments as well as the State risk assessment. The State shall estimate the potential dollar losses to State owned or operated buildings, infrastructure, and critical facilities located in the identified hazard areas.

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Avalanche

	**F**requency	50+ yrs	10-50 yrs	1-10 yrs	Annually
	People	<1,000	1,000-10,000	10,000-50,000	50,000+
	Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
	Environment	<10%	10-15%	15%-20%	20%+
	Property	<$100M	$100M-$500M	$500M-$1B	$1B+
Avalanche	Hazard scale		< Color Bar goes from Low to High >		

Risk Level

Frequency – Avalanches occur annually in Washington.

People – National and international statistics show that there is the potential for significant loss of life from an avalanche.

Economy – An incident is unlikely to cause the loss of 1% of the State GDP.

Environment – An incident is unlikely to cause the loss of 10% of a single species or habitat.

Property – An incident is unlikely to cause $100 million in damage.

HIVA Risk Classification for Avalanche is 4A or Mitigation to Reduce Risk is Optional.

Summary

The hazard – An avalanche occurs when a layer of snow loses its grip on a slope and slides downhill. Avalanches typically occur from November until early summer in all mountain areas, but year-round in high alpine areas. They primarily pose danger to people in areas where there is no avalanche control, and to continued movement of people and freight over the state's mountain highway passes.

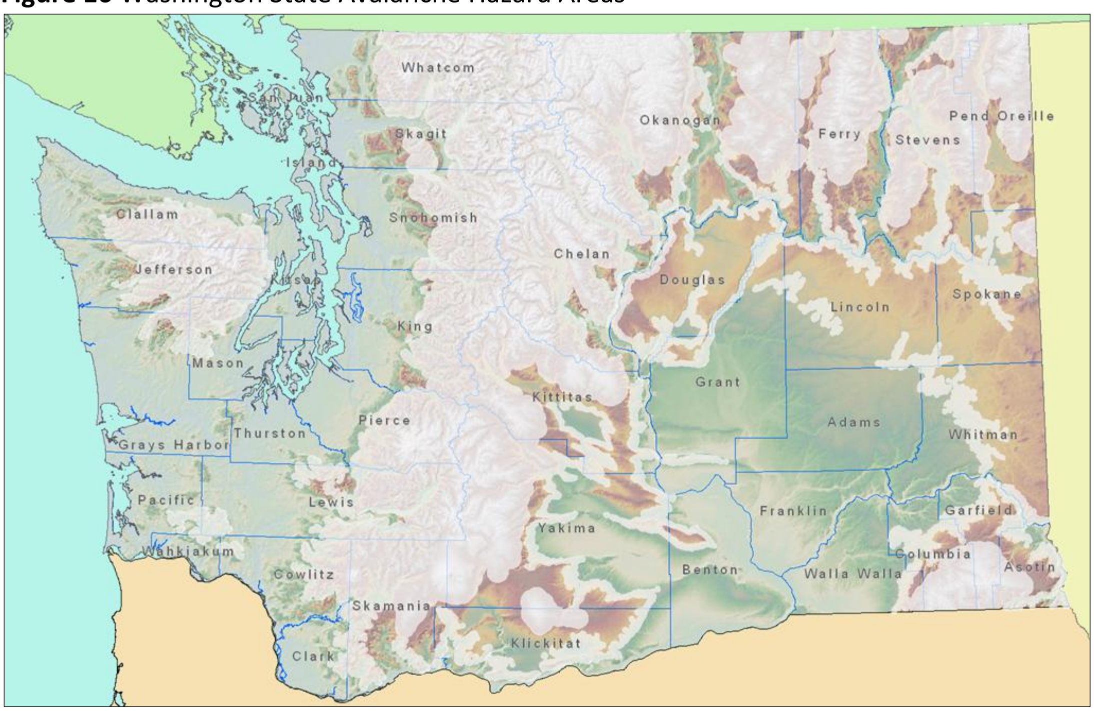
Previous occurrences – Avalanches occur frequently each year and kill one to two people annually in the Northwest (about 25-35 deaths annually in the U.S.). *Avalanches have killed more people in Washington than any other hazard during the past century*. In 90 percent of avalanche fatalities, the weight of the victim or someone in the victim's party triggers the slide.

Probability of future events – Avalanches occur regularly every year in mountain areas. Many weather and terrain factors determine actual avalanche danger. Avalanches along two key mountain highway passes are limited due to ongoing mitigation to control slides during winter months.

Jurisdictions at greatest risk – Twelve counties in which the Cascade, Olympic, Blue or Selkirk Mountains are found.

Special note – This profile will not attempt to estimate potential losses to state facilities due to avalanche. However, this hazard profile will identify a number of state highways that experience closure due to avalanches during the winter months.

Figure 16 Washington State Avalanche Hazard Areas



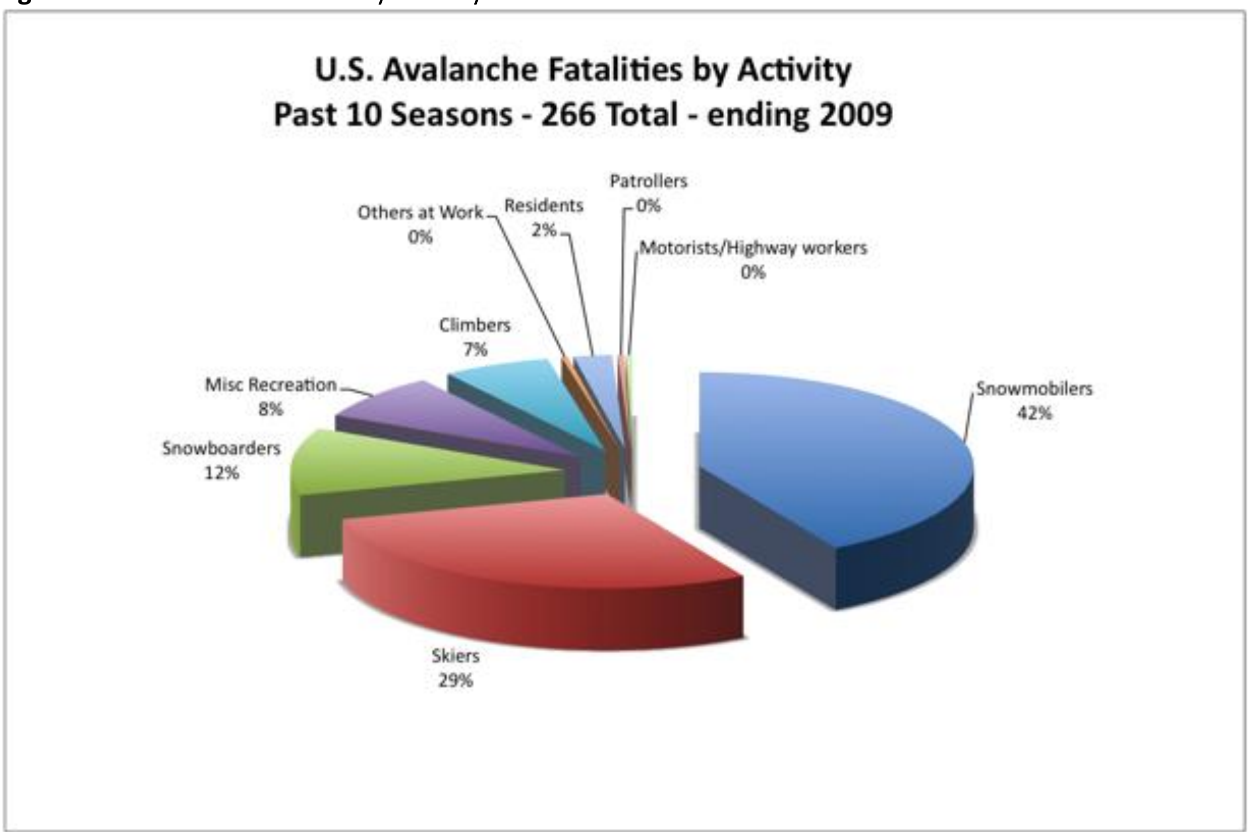
White areas on the map indicate that those areas are at least 2,000 feet in elevation and most likely to be prone to avalanches. Avalanches can and do occur outside of these areas during unusual conditions.

The Avalanche Hazard[14, 15, 16, 17, 18]

An avalanche is an often-rapid downhill motion of the snow pack or portion of the snow pack. Some wet snow or slush-flow avalanches may travel quite slowly. This motion may be natural or artificially induced, and controlled or uncontrolled in terms of time, place, and severity. An avalanche occurs when a layer of snow loses its grip on a slope and slides downhill. Avalanches have killed more than 190 people in the past century in Washington State, exceeding deaths from any other natural hazard. The nation's worst avalanche disasters occurred in 1910 when massive avalanches hit two trains stopped on the west side of Stevens Pass; at least 96 people were killed. Avalanches kill one to two people, on average, every year in Washington, although many more are involved in avalanche accidents that do not result in fatalities. Since 1985, avalanches have killed 56 people in Washington State (through March 14, 2012).

Most current avalanche victims are participating in recreational activities in the backcountry where there is no avalanche control. Only one-tenth of one percent of avalanche fatalities occurs on open runs at ski areas or on highways.

Figure 17 Avalanche Fatalities by Activity



Source: USDA Forest Service Utah Avalanche Center. (Accessed Aug. 10, 2009)
Available at: http://utahavalanchecenter.org/education/faq

Avalanches occur in four mountain ranges in the state – the Cascade Range, which divides the state east and west, the Olympic Mountains in northwest Washington, the Blue Mountains in southeast Washington, and the Selkirk Mountains in northeast Washington. The avalanche season begins in

November and continues until early summer for all mountain areas of the state. In the high alpine areas of the Cascades and Olympics, the avalanche season continues year-round.

There are two types of avalanches, loose and slab, and two types of slab avalanches, soft and hard. Avalanches can be either dry or wet. Although the most dangerous avalanche is the slab avalanche, loose slides can and do produce injury and death.

Loose avalanches occur when grains of snow cannot hold onto a slope and begin sliding downhill, picking up more snow and fanning out in an inverted V. Slab avalanches occur when a cohesive mass of snow breaks away from the slope all at once. Most slides in the Northwest are slab avalanches.

Avalanches occur for one of two basic reasons:
1) Either the load on a slope increases faster than snow strength; or
2) Snow strength decreases.

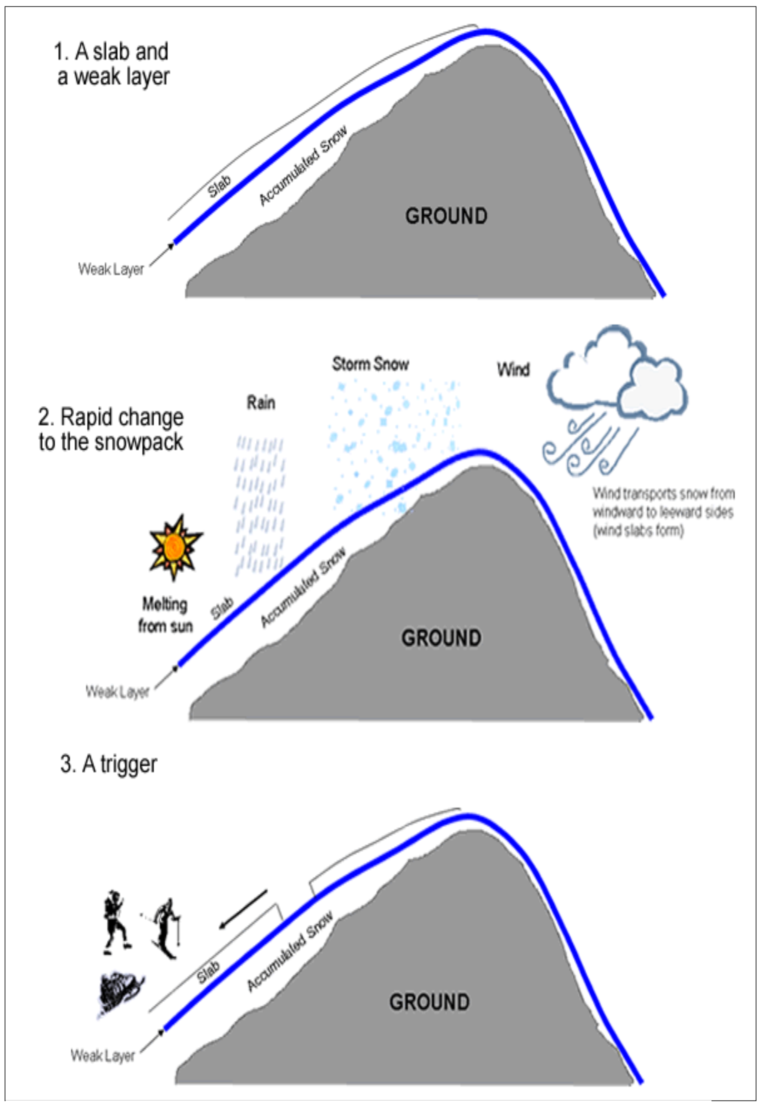


Figure 18: Ingredients for a Slab Avalanche

Slab avalanches occur when the stresses on a slab overcome the slab's attachment strength to the snow layer below. A decrease in strength is produced through warming, melting snow, or rain. Decreased strength within the existing snowpack may also result from strong temperature gradients and associated vapor transfer that produces recrystallization within the existing snow matrix. An increase in stress may be produced by the weight of additional snowfall, or a skier or a snowmobile. Dry slab avalanches can travel 60 to 80 miles per hour or more, reaching these speeds within five seconds after the fracture; they account for most avalanche fatalities. Wet slab avalanches occur when warming temperatures or rain increase the creep rate of the surface snow, putting additional forces on the slab's attachment to the layer below. When water percolating through the top slab weakens the layer and dissolves its bond with a lower layer, it decreases the ability of the weaker, lower layer to hold on to the top slab, as well as decreases the slab's strength. In 90 percent of avalanche fatalities, the weight of the victim or someone in the victim's party triggers the slide. An avalanche is like a dinner plate sliding off a table; a slab of snow shatters like a pane of glass with the victim in the middle.

Factors That Affect Avalanche Danger[19]

A number of weather, terrain and snowpack factors determine avalanche danger:

Weather:

Storms – A large percentage of all snow avalanches occur during and shortly after storms.

Rate of snowfall – Snow falling at a rate of one inch or more per hour rapidly increases avalanche danger.

Temperature – Storms starting with low temperatures and dry snow, followed by rising temperatures and wetter snow, are more likely to cause avalanches than storms that start warm and then cool with snowfall.

Wet snow – Rainstorms or spring weather with warm, moist winds and cloudy nights can warm the snow cover resulting in wet snow avalanches. Wet snow avalanches are more likely on sun-exposed terrain (south-facing slopes) and under exposed rocks or cliffs.

Wind is the most common cause of avalanches. Wind can deposit snow 10 times faster than snow falling from storms. Wind erodes snow from the upwind side of obstacles and deposits snow on the downwind (lee) side. This is called "wind loading".

Terrain:

Ground cover – Large rocks, trees and heavy shrubs help anchor snow, but also create stress concentrations between anchored and unanchored snow.

Slope profile – Dangerous slab avalanches are more likely to occur on convex slopes that produce stress concentrations within surface snow due to varying creep rates.

Slope aspect – Leeward slopes are dangerous because windblown snow adds depth and creates dense slabs. South facing slopes are more dangerous in the springtime due to increasing solar effects.

Slope steepness – Snow avalanches are most common on slopes of 30 to 45 degrees.

Snowpack:

Snow texture—the feel, appearance, or consistency of the snow determined by the shape, size and attachment of snow grains that comprise the particular snow layer. Also the inter-granular relationship— the overall feel of a snow layer, specifically the relative quantities of the different types and sizes of snow particles in a particular layer, and the size, shape and arrangement of grains as seen with a hand lens. A layer of small grained moist snow has a distinctly different texture—much more cohesive and able to make snowballs—than well faceted snow that falls apart in one's hands and exhibits very little internal cohesion.

Snow layering – The snowpack is composed of ground-parallel layers that accumulate over the winter. Each layer contains ice grains that are representative of the distinct meteorological conditions during which the snow formed and was deposited. Once deposited, a snow layer continues to evolve under the influence of the meteorological conditions that prevail after deposition.

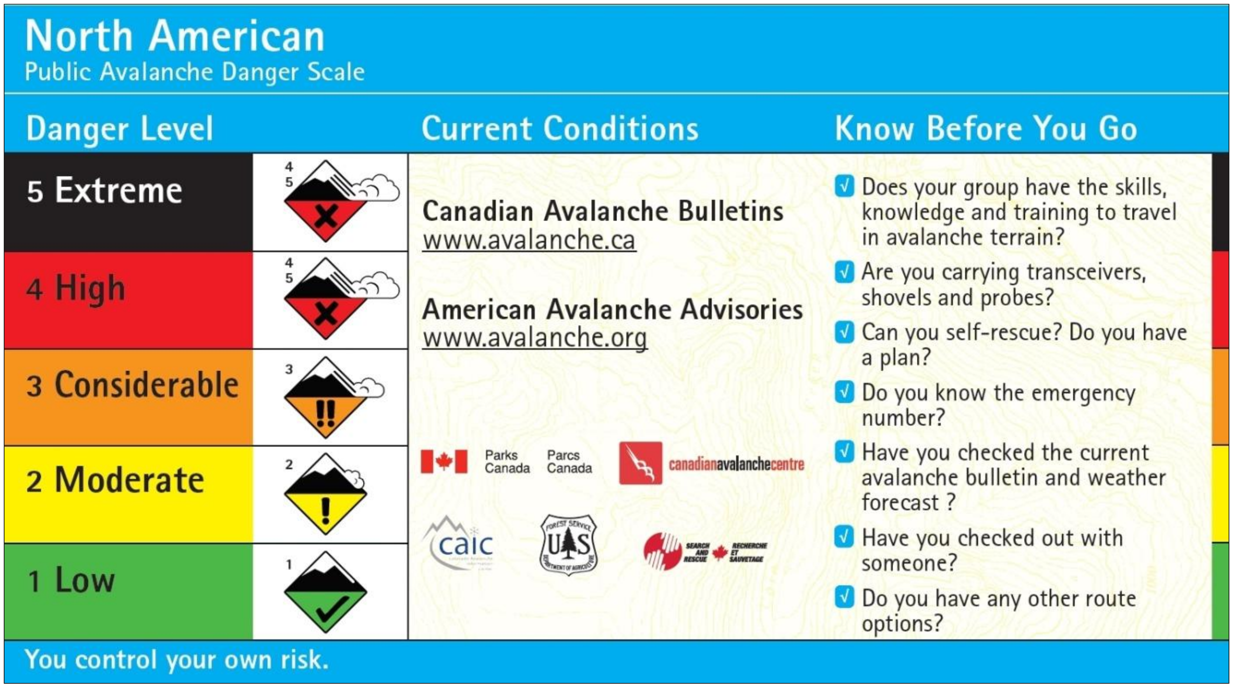
Snow bonding—in the absence of strong temperature gradients within a dry snowpack, this is the normally stabilizing or "rounding" process whereby individual snow grains or layers come into contact and gradually strengthen the ice skeleton or snow layer(s) through sintering or the formation of ice "necks" between the grains. This sintering process results from shape or size driven vapor pressure differences between or within grains or layers and involves preferential transfer of water vapor and subsequent vapor deposition. The associated redistribution of water vapor results in inter-granular attachments or bonds between grains through an expanding ice matrix, and typically results in gradual strengthening of the surrounding snowpack structure. However, it must be noted that in the presence of strong temperature gradients within or between snow layers, a different metamorphic process in the snow cover can occur which is known as faceting—a process that results in new crystal growth and/or recrystallization of existing snow grains, often producing general weakening of the snow structure. Faceting is characterized by strong (often local) temperature gradients in the snow pack and resulting strong vapor pressure gradients that move mass from warmer grains (higher vapor pressure) to colder grains (lower vapor pressure). As the process evolves and more mass is transferred, faceting snow loses existing grain bonds, forms new grains, and in general becomes more disaggregated and sugary (hence the related term "sugar snow"). In observations and tests, the hardness of a faceting snow layer decreases with time and it becomes easier to penetrate and pull individual faceted grains out of a snow pit wall.

Avalanche forecasting and control is a regular winter expense. The Washington State Department of Transportation's annual budget for removing snow and ice and for avalanche control for the highways that cross the Cascade Mountains is about $38 million. Additionally, the transportation department, ski areas, State Parks and Recreation Commission, US Forest Service, National Weather Service, National Park Service, and other agencies, help fund the Northwest Weather and Avalanche Center, which provides daily forecasts throughout the avalanche season for those involved with highway avalanche control and for recreationalists. In FY 2011 the avalanche center received approximately $603,984 in direct funding and in-kind contributions for its operations.[20]

During the avalanche season, the Northwest Weather and Avalanche Center issues twice daily mountain weather forecasts and daily (or more often) avalanche forecasts as well as special statements and avalanche warnings during times of significantly increased avalanche danger. Additionally, the NWAC maintains and manages a comprehensive network of remote mountain weather stations (see www.nwac.us/weatherdata/map/) that provide hourly weather data to users and cooperators alike.

The informational chart below details the current 2010 version of the US Danger Scale utilized by the NWAC when issuing their warnings.

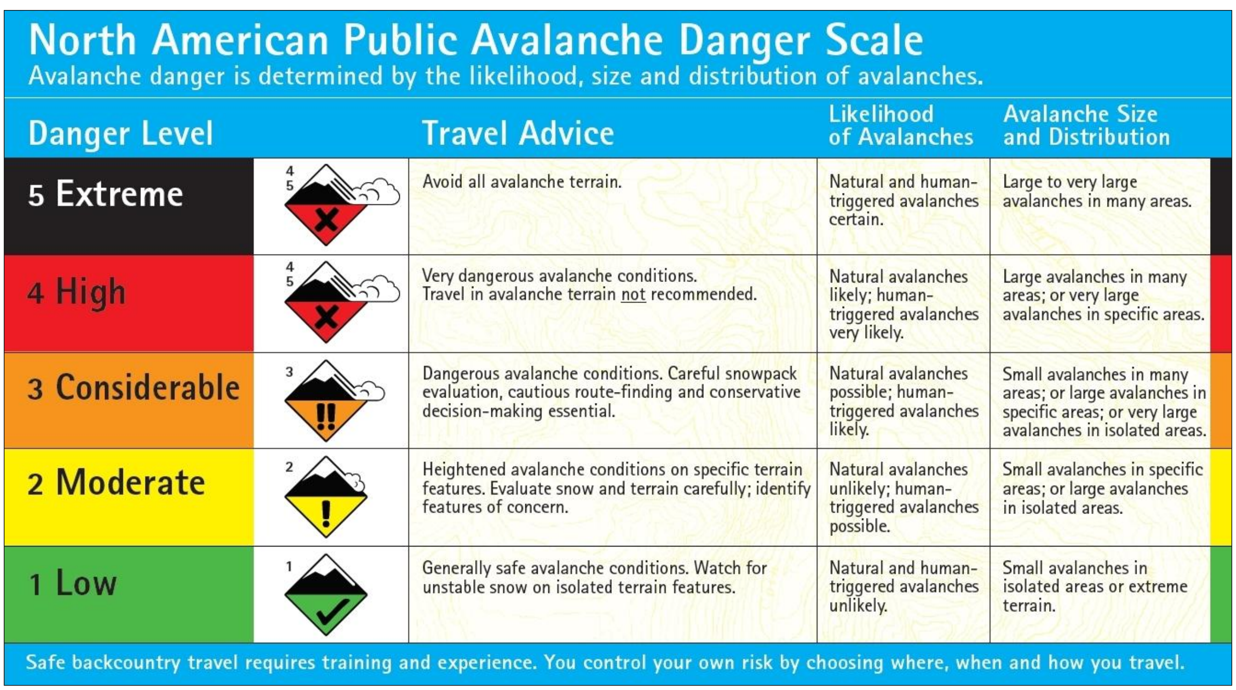
Figure 19 U.S. Danger Scale



North American
Public Avalanche Danger Scale

Danger Level	Current Conditions	Know Before You Go
5 Extreme	Canadian Avalanche Bulletins www.avalanche.ca	Does your group have the skills, knowledge and training to travel in avalanche terrain?
4 High	American Avalanche Advisories www.avalanche.org	Are you carrying transceivers, shovels and probes? Can you self-rescue? Do you have a plan?
3 Considerable		Do you know the emergency number?
2 Moderate	Parks Canada Parcs Canada canadianavalanchecentre	Have you checked the current avalanche bulletin and weather forecast ?
1 Low	caic	Have you checked out with someone? Do you have any other route options?

You control your own risk.



North American Public Avalanche Danger Scale
Avalanche danger is determined by the likelihood, size and distribution of avalanches.

Danger Level	Travel Advice	Likelihood of Avalanches	Avalanche Size and Distribution
5 Extreme	Avoid all avalanche terrain.	Natural and human-triggered avalanches certain.	Large to very large avalanches in many areas.
4 High	Very dangerous avalanche conditions. Travel in avalanche terrain not recommended.	Natural avalanches likely; human-triggered avalanches very likely.	Large avalanches in many areas; or very large avalanches in specific areas.
3 Considerable	Dangerous avalanche conditions. Careful snowpack evaluation, cautious route-finding and conservative decision-making essential.	Natural avalanches possible; human-triggered avalanches likely.	Small avalanches in many areas; or large avalanches in specific areas; or very large avalanches in isolated areas.
2 Moderate	Heightened avalanche conditions on specific terrain features. Evaluate snow and terrain carefully; identify features of concern.	Natural avalanches unlikely; human-triggered avalanches possible.	Small avalanches in specific areas; or large avalanches in isolated areas.
1 Low	Generally safe avalanche conditions. Watch for unstable snow on isolated terrain features.	Natural and human-triggered avalanches unlikely.	Small avalanches in isolated areas or extreme terrain.

Safe backcountry travel requires training and experience. You control your own risk by choosing where, when and how you travel.

Avalanche Mitigation

The Washington State Department of Transportation conducts active winter time avalanche control or mitigation on two of the state's mountain highway passes: Stevens Pass on U.S. Route 2 and Snoqualmie Pass on Interstate 90. This means avalanches are triggered intentionally on slopes above the roadways in a controlled environment to minimize traffic disruption and promote public safety. It also conducts passive avalanche control through elevated roadways so avalanches can pass under highways, over snow sheds over highways, into catchment basins to stop avalanche flow, and into diversion dams and berms to keep snow off highways. In addition to these controls the WSDOT closes three passes in winter because avalanches are so prevalent that control measures would be too costly and hazardous.[21] These passes are Chinook Pass (elevation 5,430') that connects Enumclaw and Yakima, Cayuse Pass (elevation 4,675') that connects Chinook and White Pass along the east slope of the Cascades, and Rainy/Washington Passes (elevations 4,855' and 5,500') along the North Cascades Highway, which connects the Skagit Valley to eastern Washington. This portion of the North Cascades Highway holds the distinction of being among the top areas in the United States for most avalanche chutes per mile of highway. Some areas of this highway have five avalanche paths in a mile of roadway.[22] Specific times of the winter when these passes close vary from year to year and are based on snow accumulation, personnel, avalanche risk, and a variety of other factors. Opening for the passes varies as well, although the target date for their opening is May 1 to coincide with the beginning of fishing season.

Use of explosives to prematurely trigger avalanche on Chinook Pass

Avalanche control is a winter-long task on the two primary travel corridors in Washington that must remain open all year long. The more heavily impacted corridors are Interstate 90 -Snoqualmie Pass (elevation 3,022'); the primary East-West corridor serving the Seattle-Tacoma-Olympia area and US Highway 2 - Stevens Pass (elevation 4,061') connecting Everett and Wenatchee. Snoqualmie Pass is the only interstate highway link in Washington through the Cascades. It averages 450 inches of snowfall each winter and has traffic volumes of over 32,000 vehicles a day, including 8,000 trucks. Interstate 90 is closed an average of eighty hours per year due to avalanches.[23] It is estimated that a two-hour closure of Snoqualmie pass costs the state's economy over $1 million.

Snow shed over Interstate 90 Westbound

Intermittent winter time avalanche control is also used by WSDOT along US-12 (White Pass) when conditions warrant, however, an avalanche control program for US 12 does not exist at this time. Occasional closures due to avalanche danger have occurred. Avalanche control is also done during spring time re-opening of SR 410 (Chinook and Cayuse Passes) and SR 20 (Washington Pass).

Transportation Corridor Avalanche Control[24] [25]

Snow slides are a fact of life in the Cascade Mountains. WSDOT avalanche control technicians work to reduce the potential hazard using all available experience and tools. This means operating a comprehensive program to control when and how to bring down unstable snow.

Each winter, WSDOT stations specially trained avalanche control teams at Hyak, near the I-90 Snoqualmie Pass summit and at Berne Camp, near the US 2 Stevens Pass summit. The teams work to reduce the avalanche hazard as well as the number and duration of highway closures.

Active avalanche control is when crews intentionally trigger an avalanche. To do this, WSDOT stops traffic and triggers the avalanche. Avalanche control must be done during heavy snowfall. However, to be most effective, active control work is done just as the snow is becoming unstable; but before it slides. Whenever possible, the control work is scheduled outside of peak traffic hours.

When an avalanche hazard develops, WSDOT uses artillery or explosives to trigger the avalanche. These are various methods of delivery depending on the topography and accessibility to the avalanche path. Explosives are placed by hand, cable-pulley bomb trams, or with surplus military weapons. In addition to active avalanche control, WSDOT also uses passive control methods to control snow slides. These include snow sheds over the highway; elevated roadways so avalanches pass under them, or with catchment basins to stop the avalanche before snow reaches the highway. WSDOT also uses diversion dams and snow berms to keep the snow off the highway.

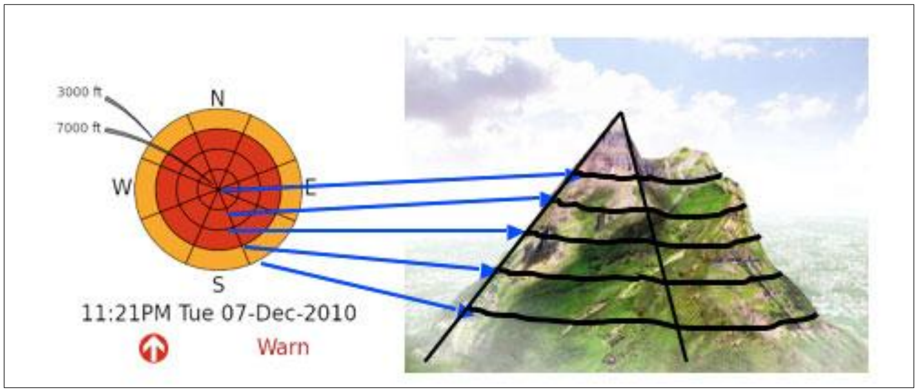
WSDOT avalanche control activity affects more than travelers. Backcountry recreation has become very popular. From the US 2/Stevens Pass Ski Area, skiers and snowboarders can access backcountry areas and potentially venture into the highway avalanche zones. WSDOT posts warning signs at the top of the ski area and in key locations, but are sometimes ignored. Besides risking injury, skiers and snowboarders sometimes trigger avalanches. They also create a hazard for themselves and others by hitchhiking back to the summit. When vehicles stop to give hitchhikers a ride, it creates a traffic hazard. The Washington State Patrol petitioned WSDOT to post the avalanche zones from milepost 58 to 66 to prohibit hitchhiking and WSP troopers vigorously enforce this ban. Skiers and snowboarders face similar personal hazards at two Snoqualmie Pass ski areas when they ignore signs and venture outside ski area boundaries.

Recreational Activity Avalanche Control

Avalanches do not happen by accident and most human involvement is a matter of choice, not chance. Most avalanche accidents are caused by slab avalanches which are triggered by the victim or a member of the victim's party. However, any avalanche may cause injury or death and even small slides may be dangerous. Hence, always practice safe route finding skills, be aware of changing conditions, and carry avalanche rescue gear. Learn and apply avalanche terrain analysis and snow stability evaluation techniques to help minimize your risk. Remember that avalanche danger rating levels are only general guidelines. Distinctions between geographic areas, elevations, slope aspect and slope angle are approximate, and transition zones between dangers exist. No matter what the current avalanche danger, there are avalanche-safe areas in the mountains.

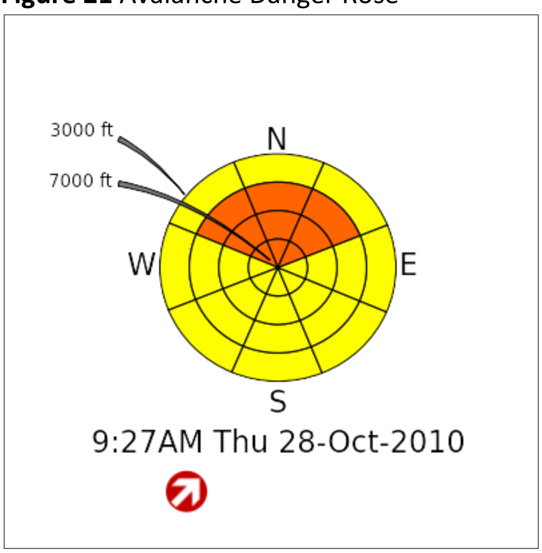
The Avalanche Danger Rose represents the highest danger level(s) expected for the indicated area (by elevation and aspect) *for the daylight hours*. The danger trend arrow (lower left part of rose graphic) indicates the most significant (highest impact) avalanche danger change expected *for the daylight hours*, ranging from strongly increasing (arrow pointing up) to strongly decreasing (arrow pointing down). Although the danger rose figures only indicate the greatest danger for the particular region for the daylight hours, danger trends for overnight hours are discussed in the text product. The danger rose can be visualized as a conical mountain within the forecast area that is divided into elevation rings and aspect slices as shown in the example. The first sample rose shown below with the mountain indicates an avalanche warning along with a strongly increasing danger trend and high danger above 4000 feet.

Figure 20 Avalanche Danger Rose



The second sample rose shown below indicates two danger levels between 3000 ft (the outermost ring) and 7000 ft (the innermost ring). The danger is moderate in yellow and considerable in orange and indicates the following danger description: *Considerable avalanche danger on northwest through northeast exposures above 4000 feet, otherwise moderate avalanche danger below 7000 feet. The slightly upward angled arrow in the left lower part of the figure indicates the most significant danger trend is for a slight danger increase during the day.*

Figure 21 Avalanche Danger Rose



Aerial Photo of 1970 Yungay, Peru Avalanche

Previous Occurrences

As shown, Washington ranks second behind Colorado in fatalities from avalanches with 187 from 1950 to 2006.[26] In the United States since the year 2000, there have been an average 200 people reported caught in avalanches each winter: 90 were partly buried or buried, 32 were injured, and 28 were fatalities. United States property losses due to avalanches in this same period ranged from a low of $30,000 to a high of $2 million. The largest accident in Washington involving an avalanche, known as the Wellington Disaster, occurred in 1910 when two trains near Stevens Pass were swept off the tracks killing 96 passengers on board. Although there is not any recorded history of a catastrophic disaster in this state from an avalanche, the potential for this hazard to cause massive destruction exists. A recent disaster from an avalanche took 50,000 lives in Iran in 1990 burying many villages in its path. The inhabitants of Yungay, Peru experienced a similar fate in 1970 when an earthquake triggered an avalanche on the slopes of Nevado de Huascarán sending millions of tons of snow into the valley below (Figure 1-4). The city and its 20,000 inhabitants were buried under 100 million cubic yards of snow, mud and rubble. Only 92 people survived.[27]

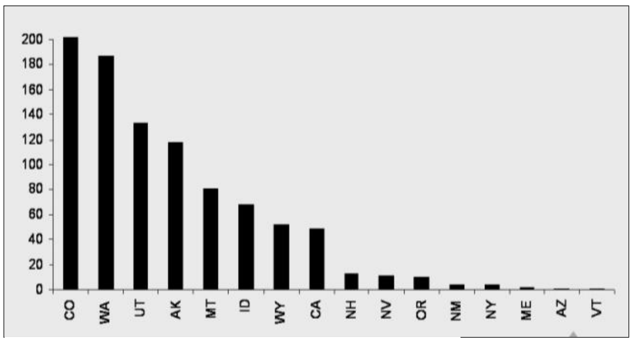


Figure 22: Avalanche Fatalities by State

Thousands of avalanches occur in the mountains of Washington every winter. Hundreds of these incidents can affect travel over the mountain pass highways, and all present the potential for accidents, delays, and fatalities to the citizens of the State. Current mitigation strategies in place lessen the potential for impact by this hazard. However, the possibility still exists for avalanches to affect the people, economy, environment, and property of Washington.

Table 16. Selected Avalanches in Washington State – 1910 to Present[28]

Date	Location	Casualties
1910	Stevens Pass	Two trains swept off their tracks, 96 dead
1939	Mount Baker	6 dead
1958	Silver Creek	4 buried
1962	Granite Mountain	2 dead
1962	Stevens Pass	2 buried
1971	Yodelin	4 dead, several buried
1974	Source Lake	2 dead
1975	Mount St. Helens	5 dead
1981	Mount Rainier	19 dead, 18 injured
1988	Mount Rainier	3 dead
1992	Mount Rainier	2 dead
1994	Mission Ridge	1 dead
1996	Index	3 dead
1996-1997	Snoqualmie Pass	Hundreds of travelers stranded after repeated avalanches closed Interstate 90 during the holidays
1998	Drop Creek	Snowmobile buried, 1 dead
1998	Mount Rainier	1 climber dead, several climbers injured
1998	Mount Baker	1 dead
1999	Mount Baker	1 snow boarder and 1 skier dead

Table 16. Selected Avalanches in Washington State – 1910 to Present[28]

2000	Crystal Mountain	1 dead
2001	Twin Lakes	2 dead
2001	Mount Baker	1 dead
2001	Lake Ann	1 dead
2002	Crystal Mountain	1 dead
2003	Snoqualmie Pass	1 snowshoer dead
2003	Mount Baker	1 snowshoer dead, 2 snowshoers injured
2003	Navajo Peak	1 snowmobiler dead
2004	Mount Baker	1 snowboarder dead
2004	Mount Rainier	2 climbers dead
2005	Snoqualmie Pass	1 skier dead
2005	Mount Baker	2 snowboarders buried – found alive by beacon (2 separate incidents/days)
2006	Mount Baker	1 skier dead
2006	Tiffany Mountain	1 snowmobiler dead
2006	Mount Hood	3 skiers buried
2007	Edit Ck Basin, Mt Rainier National Park, WA	2 snowshoers totally buried, found by probing under ~6-10 ft of snow
2007	Union Creek, south-central WA Cascades, northeast of Crystal Mt, WA	3 snowboarders dead. Group departed on weekend trip on 11/30/2007. Reported missing on 12/2/07. Subsequent searches on ground and air found no evidence of any of the group. Official search abandoned 12/8/07. Final Search and Recovery effort concluded late June, 2008 when the three missing snowboarders were found buried in avalanche debris in Union Creek.
2007	Northway at Crystal Mt Resort, WA	Two ski patrollers caught, 1 totally buried, 1 mostly buried and able to self extricate--found and rescued partner; south-central Washington Cascades at Crystal Mountain Resort, WA
2007	Snoqualmie Pass	2 hikers killed; 1 additional buried, injured & self rescued
2007	Mount Rainier	1 skier dead
2008	Rockford, WA	1 resident caught, buried and killed by roof avalanche while shoveling walk and clearing roof
2008	Tatie Peak, near Harts Pass, northern WA Cascades	1 snowmobiler dead
2008	Kahler Glen, north-central WA Cascades near Lake Wenatchee	A large natural avalanche released during the late afternoon of February 7, impacting and mostly destroying a home in the Kahler Glen development just above and west of the Kahler Glen Golf Course
2008	Lake Twenty-two trail near Mt. Pilchuck, north-central WA Cascades	8 hikers descending Lake Twenty-Two Trail; 4 in party were caught by avalanche. Slide partially buried one; totally buried three. Three were found by spot probing and survived; 1 not recovered until later by rescue team died.
2008	Excelsior Pass below Church Mtn, northern WA Cascades	5 snowmobilers high marking in the Excelsior Pass area triggered a large 5-7 ft deep slab. The avalanche caught five, partly burying one, totally burying and killing two. Victims reportedly found by beacon and probing under three and six feet of snow.

Table 16. Selected Avalanches in Washington State – 1910 to Present[28]

2009	Hogsback Mtn, south-central WA Cascades	One skier caught and completely buried under ~2.5 ft of snow. Found by partner's beacon and recovered within about 10 minutes.
2010	Morning Star Peak, north-central WA Cascades	One hiker/climber caught, partially buried and killed; dog recovered alive
2011	Hooky Bowl on Trout Ck drainage, near Mt Cashmere, east slopes central WA Cascades	1 BC skier in a group of 5 triggered and caught by slide, carried through trees and fatally injured. Found deceased on the surface by party members.
2011	Backside of Cowboy Mtn toward Tunnel Ck, west of Stevens Pass Ski Area, north central WA Cascades	Snowboarder triggered and caught by wet loose slide, swept into tree band and fatally injured. Found quickly by party members but failed to respond to CPR
2012	Tunnel Creek draining west of Stevens Pass Mountain Resort, north-central WA Cascades	Four skiers triggered and caught by 2-3 foot slab while skiing the Tunnel Creek back country off Cowboy Mountain to the SSW of the ski area. Three buried and killed (combination of trauma and suffocation), one survived with air bag deployed.
2012	WAC Bluff area, east of Alpental Ski Area, central WA Cascades, WA	Three snowboarders entered the 80s chute in the back country to the east of Alpental Ski Area, triggering a slide. The slide caught two, one of whom was able to self arrest. The other boarder was carried over a steep cliff chute and died from trauma.

Probability of Future Events

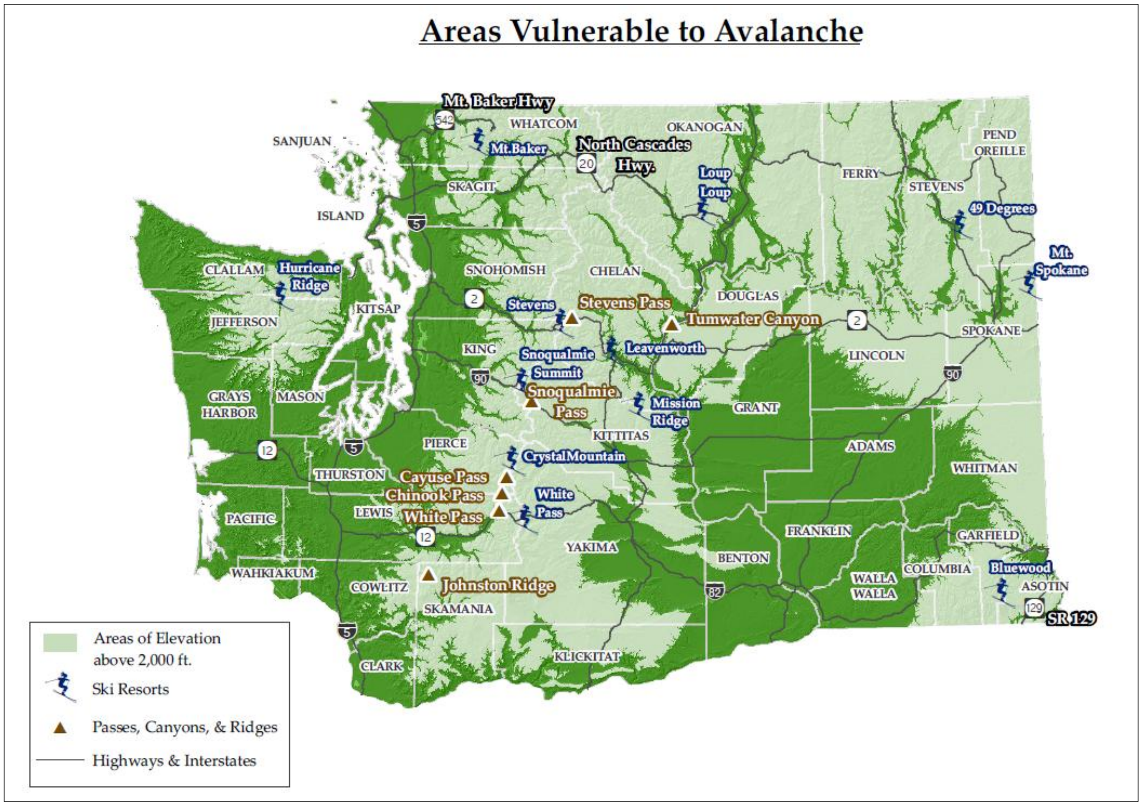
Avalanches occur regularly every year in mountain areas. Many weather, snowpack and terrain factors determine actual avalanche danger. Avalanches along two key mountain highway passes are limited due to ongoing mitigation to control slides during winter months. Nonetheless, those highways do get closed regularly for control work and cleanup. Recreation activity in backcountry areas results in countless avalanches and a few deaths each year.

Jurisdictions Most Vulnerable to Avalanches

Based on the location of key transportation routes and recreational areas threatened by avalanche, parts of the following counties are most vulnerable to avalanche:

Asotin	Chelan	Ferry	Garfield	King	Kittitas	Klickitat	Lewis
Okanogan	Pend Oreille	Pierce	Skagit	Skamania	Snohomish	Whatcom	Yakima

Figure 23 Areas Vulnerable to Avalanche



***Transportation routes threatened by avalanche*[29, 30, 31.]**

Highway closures due to avalanche can have a significant economic impact on the state. Economists estimate that closing Interstate 90 over Snoqualmie Pass has an economic cost to the state of between $500-750,000 per hour for stalled shipping, lost perishables, and rerouting. During the winter of 1996-97, there were 276 hours of closure of I-90 over Snoqualmie Pass, 70 percent related to avalanche control and avalanche safety closures; these closures were more than in any other year in recent times. The closures cost the state's economy an estimated $144 million (in 2002 dollars).

The Washington Department of Transportation spends considerable effort each winter keeping the following mountain passes open and free from avalanches:

King County – Snoqualmie Pass I-90, Stevens Pass US 2.

Kittitas County – Snoqualmie Pass I-90, Blewett Pass US 97.

Chelan County – Stevens Pass and Tumwater Canyon US 2.

Passes closed all winter with spring openings that have residual avalanche hazard after they are open are:

Pierce, Yakima Counties – Chinook Pass SR 410, Cayuse Pass SR 123.

Skagit, Okanogan Counties – North Cascades Highway SR 20.

Mountain passes and highways that pose avalanche problems or that have the potential for problems in the worst conditions are:

Lewis and Yakima Counties – White Pass US 12.
Skagit County – Diablo Canyon SR 20.
Skamania County – Johnston Ridge, SR 504.
Asotin County – SR 129 south of Anatone.
Whatcom County – SR 542 to the Mount Baker Ski Area.

***Recreation areas threatened by avalanche*[32]**

With better equipment allowing more people to explore further into the wilderness, areas threatened by avalanche are those accessible by skiers, snowshoers, snowboarders, climbers, hikers and snowmobilers outside developed ski resorts in the mountains of Washington. This includes the areas that people can reach via Sno-Parks (parking lots cleared of snow) in Asotin, Chelan, Ferry, Garfield, King, Kittitas, Klickitat, Lewis, Okanogan, Pend Oreille, Pierce, Skagit, Skamania, Snohomish, Whatcom, and Yakima counties; Hurricane Ride in Olympic National Park (Clallam County) is another area providing easy access to avalanche-prone terrain (see map generally depicting areas at-risk to avalanche below).

State Agency Structures at Risk to Avalanche

Table 17: State Agency Structures At Risk to Avalanche

Number and Function of Buildings	No. of Affected Staff / Visitors / Residents	Approx. Value of Owned Structures	Approx. Value of Contents
0	0	0	0
However, WSDOT has identified a number of state highways as being at risk to avalanche: Asotin County – SR 129 south of Anatone. Chelan County – Stevens Pass and Tumwater Canyon US 2. King County – Snoqualmie Pass I-90, Stevens Pass US 2. Kittitas County – Snoqualmie Pass I-90, Blewett Pass US 97. Lewis and Yakima Counties – White Pass US 12 and SR 410. Pierce County – Chinook Pass SR 410, Cayuse Pass SR 123. Skagit County – North Cascades Highway SR 20. Skamania County – Johnston Ridge, SR 504. Whatcom County – SR 542 to the Mount Baker Ski Area.			
Four state highways considered emphasis corridors because of their importance to movement of people and freight have been identified as being at risk to avalanche: U.S. Highway 2 U.S. Highway 12 Interstate 90 U.S. Highway 97			

Potential Climate Change Impacts[33,34,35,36]

With the advent of climate change coming into worldwide focus; it is necessary to take into account the potential effects this emerging climate crisis may have on the dangers associated with avalanches. The research done so far indicates the potential for avalanches to become more frequent and deadly, as global warming effects the melting of permafrost, the permanent frozen layer of snow that gives our mountains and peaks their distinctive look. Already, the melting of permafrost can be blamed on several recent Alpine disasters, including the avalanches which killed more than 50 people at the Austrian resort of Galtur in 1999.[37]

According to a 2005 Governor's report prepared by the Climate Impacts Group titled *Uncertain Future: Climate Change and its Effects on Puget Sound*, from "paleoclimatological evidence, we know that over the history of the earth high levels of greenhouse gas concentrations have correlated with, and to a large extent caused, significant warming to occur, with impacts generated on a global scale." While the report also indicates that the "ultimate impact of climate change on any individual species or ecosystem cannot be predicted with precision," there is no doubt that Washington's climate has demonstrated change.

In July 2007, the Climate Impacts Group launched an unprecedented assessment of climate change impacts on Washington State. *The Washington Climate Change Impacts Assessment* (WACCIA) involved developing updated climate change scenarios for Washington State and using these scenarios to assess the impacts of climate change on the following sectors: agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon, and urban stormwater infrastructure. The assessment was funded by the Washington State Legislature through House Bill 1303.

In 2009, the Washington State Legislature approved the *State Agency Climate Leadership Act* Senate Bill 5560. The Act committed state agencies to lead by example in reducing their greenhouse gas (GHG) emissions to: 15 percent below 2005 levels by 2020; 36 percent below 2005 by 2035; and 57.5 percent below 2005 levels (or 70 percent below the expected state government emissions that year, whichever amount is greater.). The Act, codified in RCW 70.235.050-070, directed agencies to annually measure their greenhouse gas emissions, estimate future emissions, track actions taken to reduce emissions, and develop a strategy to meet the reduction targets. Starting in 2012 and every two years thereafter, each state agency is required to report to Washington State Department of Ecology the actions taken to meet the emission reduction targets under the strategy for the preceding biennium.

Recognizing Washington's vulnerability to climate impacts, the Legislature and Governor Chris Gregoire directed state agencies to develop an integrated climate change response strategy to help state, tribal and local governments, public and private organizations, businesses and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy*.

Over the next 50 - 100 years, the potential exists for significant climate change impacts on Washington's coastal communities, forests, fisheries, agriculture, human health, and natural disasters. These impacts could potentially include increased annual temperatures, rising sea level, increased sea surface temperatures, more intense storms, and changes in precipitation patterns. Therefore, climate change has the potential to impact the occurrence and intensity of natural disasters, potentially leading to additional loss of life and significant economic losses. Recognizing the global, regional, and local implications of climate change, Washington State has shown great leadership in addressing mitigation through the reduction of greenhouse gases.

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Drought

Drought

Frequency	50+ yrs	10-50 yrs	1-10 yrs	Annually
People	<1,000	1,000-10,000	10,000-50,000	50,000+
Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
Environment	<10%	10-15%	15%-20%	20%+
Property	<$100M	$100M-$500M	$500M-$1B	$1B+
Hazard scale		< Color Bar goes from Low to High >		

Risk Level[38]

Frequency – Based on the 100-year history of drought in Washington, the state as a whole can expect severe or extreme drought conditions at least every five years, with most of eastern Washington experiencing severe or extreme drought more frequently.

People – While people are definitely affected by a drought, lives are usually not lost due to this hazard.

Economy – The two worst droughts in the state's history (1977 and 2001) resulted in thousands of job losses to the power and agricultural industries as well as job losses in the mining, recreation, and fishing industries. In addition, the estimated losses to the state's economy due to these two drought events were close to $500 million.

Environment – While the presence of drought can increase the likelihood of wildfires and result in significant damage to the environment, this damage is not expected to completely alter 10% of a habitat or eradicate 10% of a single species, and therefore does not meet the minimum threshold for this category.

Property – During Washington's last drought in 2005, the Washington State Department of Agriculture (WSDA) made a preliminary estimate of the potential impact of this drought on Washington's agriculture industry. Assuming a worst-case scenario of below average precipitation throughout the growing season, WSDA anticipated that crop losses would be between $195 and $299 million, or 5 to 8% of the Washington harvest.

HIVA Risk Classification for Drought is 2B or Mitigation to Reduce Risk is Required.

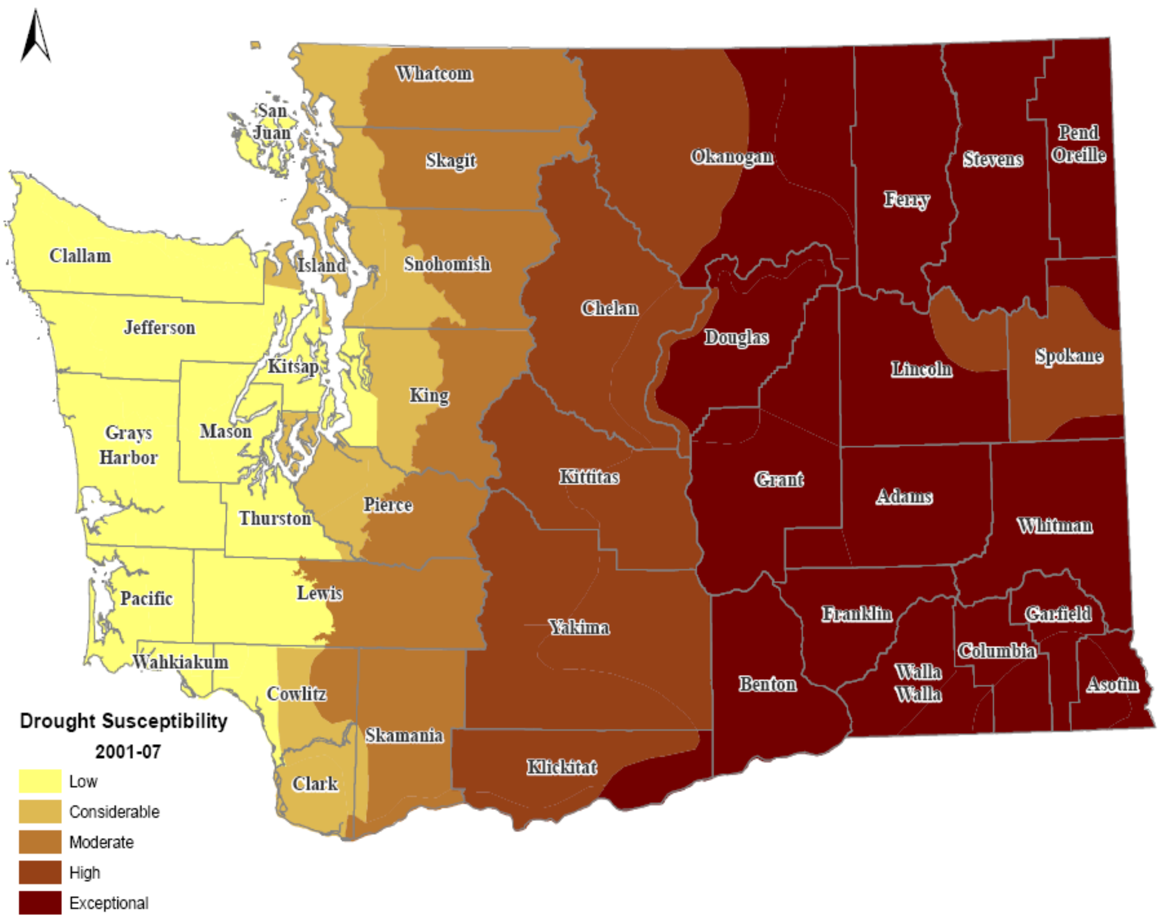


Figure 24 Drought Susceptibility for Washington State 2001-2007

Summary

The hazard – Drought is a prolonged period of low precipitation severe enough to reduce soil moisture, water and snow levels below the minimum necessary for sustaining plant, animal, and economic systems. A natural part of the climate cycle, droughts can reduce water supply, threaten crops that rely on natural precipitation, and increase the threat of wildfires.

Previous occurrences – Washington has a history of drought, including several that lasted more than a single season. The worst two on record occurred in 1977 and 2001; the most recent event was in 2005.

Probability of future events – At this time, reliable forecasts of drought are not attainable for temperate regions of the world more than a season in advance. However, based on a 100-year history with drought, the state as a whole can expect severe or extreme drought at least 5 percent of the time in the future, with most of eastern Washington experiencing severe or extreme drought about 10 to 15 percent of the time.

Jurisdictions at greatest risk – Nine counties meet criteria including percentage of time in drought, water use for crop irrigation or due to growth, and potential inability to deal with financial impacts of drought on their communities.

Special note – This profile will not attempt to estimate potential losses to state facilities due to drought. This hazard poses little threat to people and the built environment, but can pose significant damage to the state's economy.

The Drought Hazard[39, 40, 41, 42, 43, 44, 45]

Drought is a prolonged period of reduced precipitation severe enough to reduce soil moisture, water and snow levels below the minimum necessary for sustaining plant, animal, and economic systems. Droughts are a natural part of the climate cycle. In the past century, Washington State has experienced a number of drought episodes, including several that lasted for more than a single season – 1928 to 1932, 1992 to 1994, and 1996 to 1997.

Unlike most states, Washington has a statutory definition of drought (Revised Code of Washington Chapter 43.83B.400). According to state law, an area is in a drought condition when:
The water supply for the area is below 75 percent of normal.
Water uses and users in the area will likely incur undue hardships because of the water shortage.

Drought can have a widespread impact on the environment and the economy, depending upon its severity, although it typically does not result in loss of life or damage to real property, as do other natural disasters.

The National Drought Mitigation Center at the University of Nebraska-Lincoln uses three categories to describe likely drought impacts:

Agricultural – Drought threatens crops that rely on natural precipitation.

Water supply – Drought threatens supplies of water for irrigated crops and for communities.

Fire hazard – Drought increases the threat of wildfires from dry conditions in forest and rangelands.

Additionally, drought threatens the supply of electricity in our state. Hydroelectric power plants generated nearly three-quarters of the electricity produced in Washington State in 2000. When supplies of locally generated hydropower shrink because of drought, utilities seek other sources of electricity, which can drive up prices even as supply is reduced.

Unlike most disasters, droughts occur slowly but may last a long time. On average, the nationwide annual economic impacts of drought – between $6 billion and $8 billion annually in the United States – are greater than the impacts of any other natural hazard. They occur primarily in the agriculture, transportation, recreation and tourism, forestry, and energy sectors. Social and environmental impacts are also significant, although it is difficult to put a precise cost on these impacts.

Drought affects groundwater sources, but generally not as quickly as surface water supplies, although groundwater supplies generally take longer to recover. This can lead to a reduction in groundwater levels and problems such as reduced pumping capacity or wells going dry; shallow wells are more susceptible than deep wells. About 16,000 drinking water systems in Washington State get water from the ground; these systems serve about 5.2 million people.

Reduced replenishment of groundwater affects streams. Much of the flow in streams comes from groundwater, especially during the summer when there is less precipitation and after snowmelt ends. Reduced groundwater levels mean that even less water will enter streams when steam flows are lowest.

The Washington State's climate and ecology are largely shaped by the interactions that occur between seasonally varying weather patterns and the region's mountain ranges. Approximately two-thirds of the region's precipitation occurs in October-March. Much of this precipitation is captured in the region's mountains. Unlike other parts of the country, snow- rather than man –made reservoirs- is the dominant form of water storage, storing water from the winter and releasing it in spring and early summer, when economic, environmental, and recreational demands for water are greatest throughout the state.

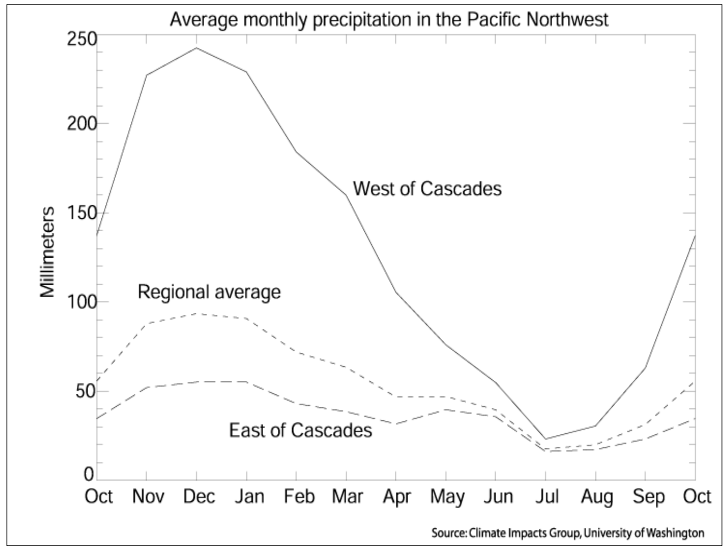


Figure 25 Average Monthly Precipitation in the Pacific Northwest for 1900-1998

The amount of snow that collects in Washington's mountains largely depends on both precipitation and the temperature during winter months. The El Niño – Southern Oscillation (El Niño/ La Niña) events that occur in the Pacific Ocean affect Washington's winter weather and play a role in whether the region experiences a drought. In El Niño years, winters tend to be drier and temperatures tend to be warmer, the result is lower springtime snowpack and lower stream flow during spring and summer in snowmelt driven rivers.

A drought directly or indirectly affects all people and all areas of the state. A drought can result in farmers not being able to plant crops or the failure of the planted crops. This results in loss of work for farm workers and those in related food processing jobs. Other water or electricity-dependent industries commonly shut down all or a portion of their facilities, resulting in further layoffs. A drought can spell disaster for recreational companies that use water (e.g., swimming pools, water parks, and river rafting companies) and for landscape and nursery businesses because people will not invest in new plants if water is not available to sustain them. Also, people could pay more for water if utilities increase their rates. With much of Washington's energy coming from hydroelectric plants, a drought can mean more expensive electricity from other resources than dams and probably higher electric bills.

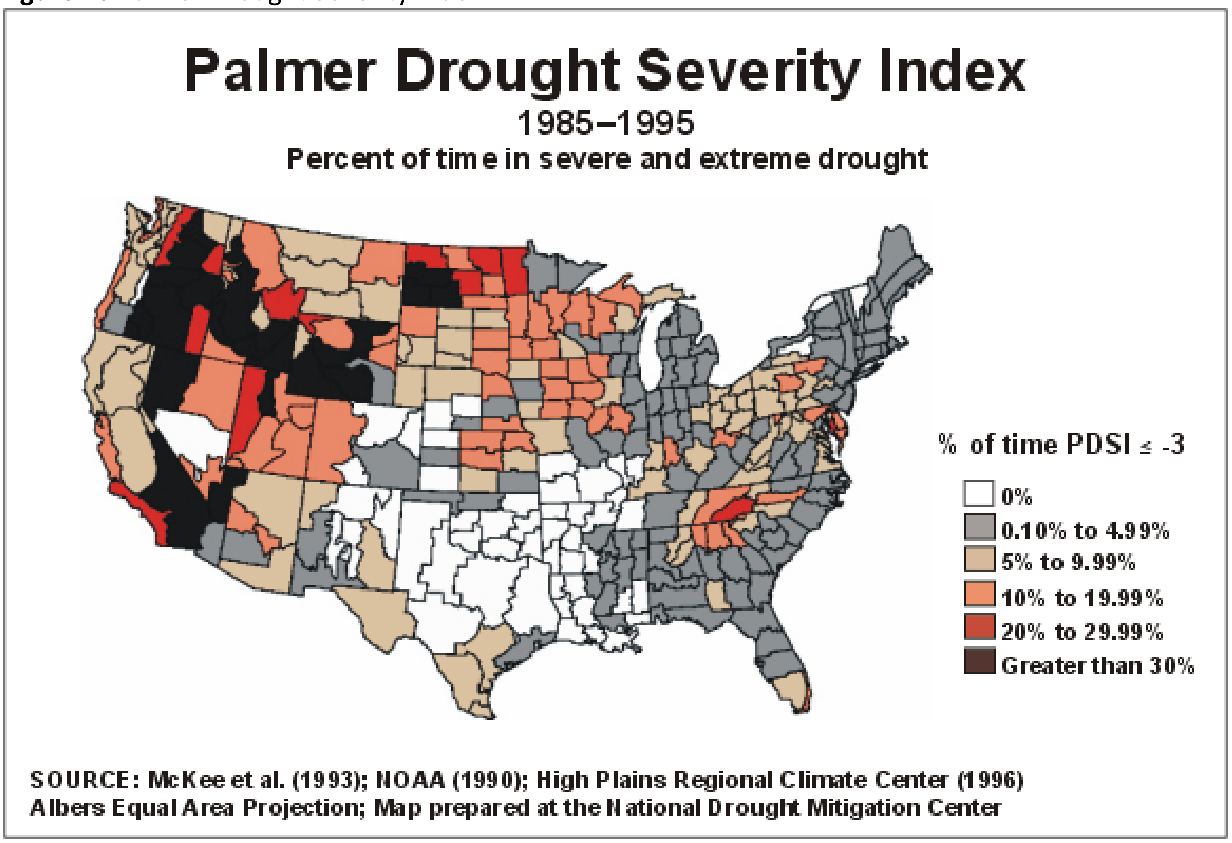
Previous Occurrences[46]

Empirical studies conducted over the past century have shown that meteorological drought is never the result of a single cause. It is the result of many causes, often synergistic in nature; these include global weather patterns that produce persistent, upper-level high-pressure systems along the West Coast with warm, dry air resulting in less precipitation.

Scientists at this time do not know how to predict drought. Predicting drought depends on the ability to forecast precipitation and temperature. Anomalies of precipitation and temperature may last from several months to several decades. How long they last depend on interactions between the atmosphere and the oceans, soil moisture and land surface processes, topography, and the accumulated influence of weather systems on a global scale.

The U.S. Drought Monitor is produced in partnership between the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration. One of the key tools used is the Palmer Drought Severity Index. Drought intensity categories are based on five key indicators and numerous supplementary indicators. Additional indicators are often needed in the West, where winter snowfall has a strong bearing on water supplies. The weekly produced Drought Monitor is intended to provide a general and up-to-date summary of current drought conditions across the 50 states, Puerto Rico, and the Pacific possessions. This national product is designed to provide the "big picture".

Figure 26 Palmer Drought Severity Index



In temperate regions, including Washington State, current long-range forecasts of drought have limited reliability. In the tropics, empirical relationships have been demonstrated between precipitation and El Niño events, but few such relationships have been demonstrated above the 30º north latitude; Washington State sits between 45.30º and 49º north latitude. Meteorologists do not believe that reliable drought forecasts are attainable a season or more in advance for temperate regions.

Based on the state’s history with drought from 1895 to 1995, the state as a whole can expect severe or extreme drought at least 5 percent of the time in the future. All of eastern Washington, except for the eastern foothills of the Cascade Mountains, can expect severe or extreme drought 10 to 15 percent of the time. The east slopes of the Cascades and much of western Washington can expect severe or extreme drought from 5 to 10 percent of the time.

Comparing the droughts of 1977 and 2001[47, 48]

The Northwest typically has a dry summer with very little summer rainfall. In Seattle, the average rainfall for July is less than one inch while it is nearly six inches in November. Most of the state's annual precipitation occurs during the winter. Precipitation in the Cascade Mountains is normally stored as snow that slowly melts during the spring and summer, maintaining stream and river flows. This is the primary source of water for irrigation and municipal use. The major causes of droughts in Washington are either low snow accumulations from either low precipitation or warm winter temperatures; or by warm weather in the late winter-early spring that causes early melt of the snowpack.

Where the snow falls affects the nature of a drought. The Columbia River provides most of the energy for hydroelectric power and irrigation for the Columbia Basin Project and farms in the basin. The Columbia receives large amounts of its flow from mountainous areas in British Columbia. In the southern Cascade Mountains of Washington, the Yakima River basin is particularly influenced by fluctuating snow levels.

The 1977 drought was the worst on record, but the 2001 drought came close to surpassing it in some respects. The table below has data on how the two droughts affected Washington by late September of their respective years.

Table 18. Comparison of Impacts of 1977 Drought and 2001 Drought Events

	1977 Drought	2001 Drought
Precipitation	Precipitation received at most locations ranged from 50 to 75 percent of normal levels, and in parts of Eastern Washington as low as 42 to 45 percent of normal.	Precipitation was 56 to 74 percent of normal. US Bureau of Reclamation – Yakima Project irrigators received only 37 percent of their normal entitlements. At the end of the irrigation season, the U.S. Bureau of Reclamation's five reservoirs stored only 50,000 acre-feet of water compared with 300,000 acre-feet typically in storage.
Wildland Fire	1,319 wildland fires burned 10,800 acres. State fire-fighting activities involved more than 7,000-man hours and cost more than $1.5 million.	1,162 wildland fires burned 223,857 acres. Firefighting efforts cost the state $38 million and various local, regional and federal agencies another $100 million.
Fish	In August and September 1977, water levels at the Goldendale and Spokane trout hatcheries were down. Fish had difficulties passing through Kendall Creek, a tributary to the north fork of the Nooksack River in Whatcom County.	A dozen state hatcheries took a series of drought-related measures, including installing equipment at North Toutle and Puyallup hatcheries to address low water flow problems.

Table 18. Comparison of Impacts of 1977 Drought and 2001 Drought Events

	1977 Drought	2001 Drought
Emergency Water Permits	Department of Ecology issued 517 temporary ground-water permits to help farmers and communities drill more wells.	Department of Ecology issued 172 temporary emergency water-right permits and changes to existing water rights.
Economic Impacts	The state's economy lost an estimated $410 million over a two-year period. The drought hit the aluminum industry hardest, with major losses in agriculture and service industries, including a $5 million loss in the ski industry. 13,000 jobs were lost because of layoffs in the aluminum industry and in agriculture.	The Bonneville Power Administration paid more than $400 million to electricity-intensive industries to shut down and remain closed for the duration of the drought. Thousands lost their jobs for months including 2,000-3,000 aluminum smelter workers at the Kaiser and Vanalco plants. Federal agencies provided more than $10.1 million in disaster aid to growers. More than $7.9 million in state funds paid for drought-related projects; these projects enabled the state to provide irrigation water to farmers with junior water rights and to increase water in fish-bearing streams.

In examining the impact of the 2001 drought, the Washington Department of Agriculture determined the potential long-term economic impact of cutting off water to a group of irrigators was five times the value of the lost harvest. The analysis examined the production of 330 farmers that irrigated and harvested nearly 38,000 acres of cropland in the Columbia-Snake River region. The analysis assumed: The farms would not receive sufficient water to maintain their plants for one year; Annual crop farmers, representing about 70 percent of the acres, suffered a single year loss; and Perennial-crop farmers (apples, cherries, grapes, etc.) lost production for three to seven years.

Table 2, below, shows the value of the economic loss for these farmers was projected at $1.2 billion, with projected annual job losses ranging from 2,144 the first year to 643 in subsequent years; each $1 million in lost economic activity represents approximately 15 jobs.

Table 19. Economic Impact of Drought on 330 Irrigators in Columbia-Snake System

Year	Acres Affected	Value Lost Harvest		Replanting Cost		Total Direct Loss (millions)	Job Loss			Total Economic Loss (millions)
		Harvest / Acre	**Value** (millions)	Cost/ Acre	**Value** (millions)		On Farm	Related Jobs	Annual Total	
2001	37,806	$1,755	$66.3	$350	$4.0	$70.3	991	1,153	2,144	$331.7
2002	11,342	$4,000	$45.4	$9,638	$109.3	$154.7	297	346	643	$226.8

Table 19. Economic Impact of Drought on 330 Irrigators in Columbia-Snake System

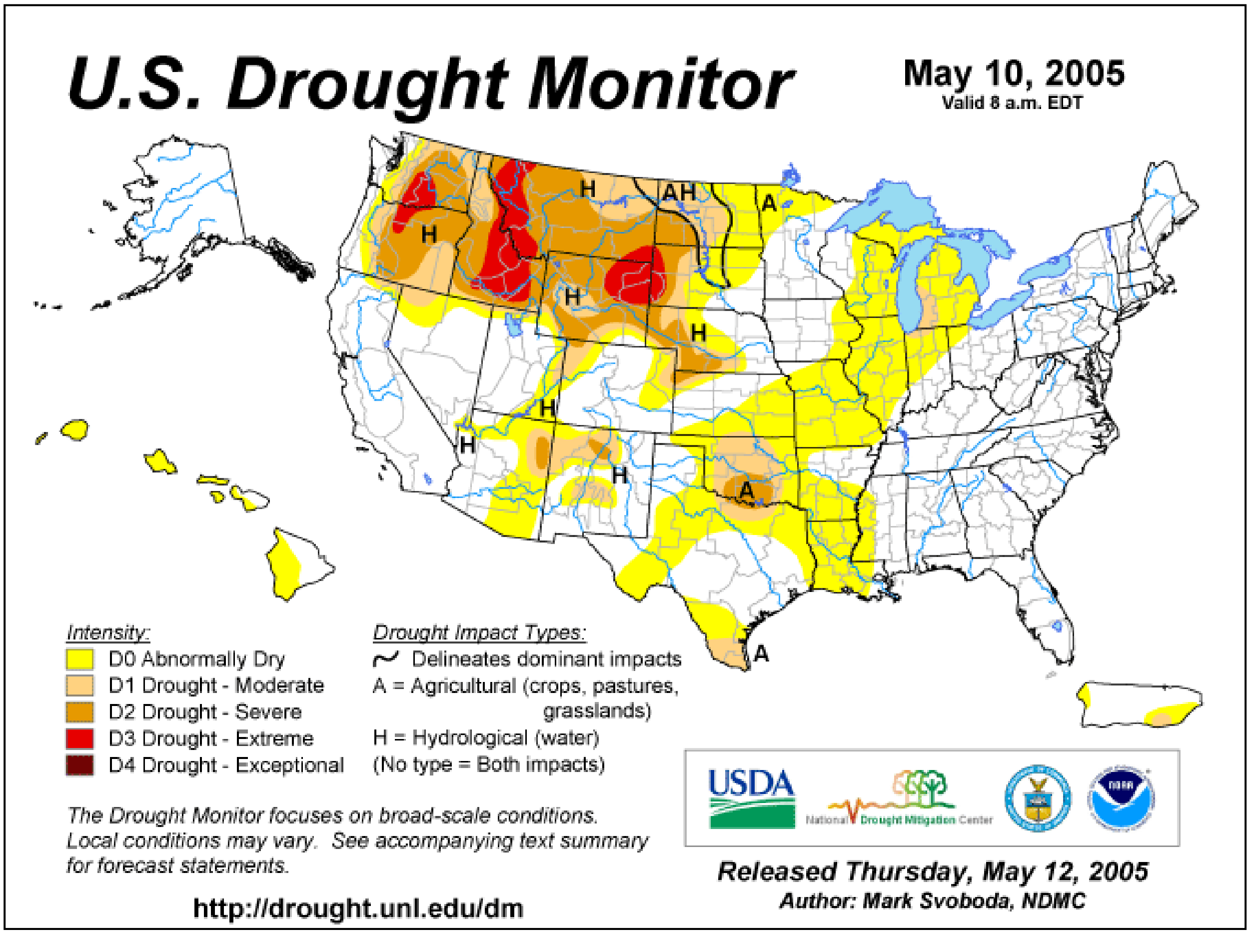
2003	11,342	$4,000	$45.4	$858	$9.7	$55.1	297	346	643	$226.8
2004	11,342	$4,000	$45.4	$750	$8.5	$53.9	297	346	643	$226.8
2005	11,342	$4,000	$45.4	$184	$2.1	$47.5	297	346	643	$226.8
Total Harvest Loss			$247.8		$133.6	$381.4				$1,239.1

Source: Washington Department of Agriculture, The Impact of the 2001 Drought on Washington Agriculture.

2005 Drought[49]

October precipitation ranged between normal to well-above normal for all but the north Puget Sound region. However, precipitation was below or much below average November through February for much of the state, and the fall and winter months were extremely warm, which adversely affected the state's mountain snow pack. A warm mid-January storm removed much of the remaining snow pack. February turned out to be warm and dry. By early March, projections showed Washington might be facing a drought as bad as or worse than the 1977 drought, the worst on state record.

Figure 26 U.S. Drought Monitor



Governor Christine Gregoire authorized the Department of Ecology to declare a statewide drought emergency on March 10, 2005.

Consequently, the state legislature approved a $12 million supplemental budget request that provided funds for buying water, improving wells, implementing other emergency water-supply projects, and hiring temporary state staff to respond to the drought emergency, conduct public workshops and undertake drought-related studies.

In March, the water supply forecast was 66 percent of normal, signaling an extremely poor water year and a possible reduction in electricity production. By late spring, due to record precipitation in March and April, water filled reservoirs to about 95 percent of capacity, more than enough to meet projected electricity demands. Despite projected drought impacts of up to $300 million, unexpected spring rains combined with reallocation of water and conservation measures by farmers largely mitigated the drought's impacts. Harvest of most crops was near normal levels. While statewide harvests were near normal, local farmers who did not receive the spotty rains experienced poor harvests. The number of wildfires was about 75 percent of average for the previous five years, but the acreage burned was three times greater. The largest – the School fire – burned 52,000 acres of state-protected lands, 109 homes and 106 other buildings, and cost more than $15 million to extinguish. The fire also destroyed half of the elk and bighorn sheep and a third of the deer in the Tucannon Game Management Unit.

In October, Governor Gregoire requested agricultural disaster designations from the U.S. Secretary of Agriculture because of significant crop damage from drought. The following counties were included in the disaster request: Asotin, Benton, Chelan, Clark, Columbia, Cowlitz, Douglas, Franklin, Kittitas, Klickitat, Lincoln, Skamania, Walla Walla, Wahkiakum, and Yakima. The emergency proclamation for the drought expired on December 31, 2005.

Impact of Drought on the Washington's Agriculture Industry[50, 51, 52]

Agriculture is the industry most heavily affected by drought. Most of Washington's crops grow in near-desert conditions in Eastern Washington and depend on irrigation; three-quarters of the water consumed in Washington State is used for irrigating crops, according the U.S. Geological Survey.

The state's food and agriculture industry support more than 180,000 jobs around the state and generates 13 percent of the state's economy. Almost 70 percent of Washington's crop value – about $3.6 billion – comes from the 27 percent of harvested cropland that is irrigated. This includes the most valuable crops: apples, cherries, other tree fruit, vegetables, onions and potatoes. Per acre, irrigated crops are worth almost seven times more than crops from non-irrigated land. The tree fruit industry is the largest single user of irrigation water.

According to the 2005 and 2006 production estimates from the U.S. Department of Agriculture (USDA), Washington State was the top producer of apples and pears in the nation, was the number-two producer of sweet cherries, plums, prunes and potatoes, and the seventh-ranked producer of vegetables. In 2011 USDA reported that Washington State was the top producer of apples in the nation, valued at $1.83 billion. Milk was ranked second, wheat third, potatoes fourth, and hay was the fifth leading agricultural commodity produced in Washington State. Overall, field crops were valued at $3.24 billion, fruit and nut crops at $2.50 billion, livestock at $2.39 billion, commercial vegetables at $481 million and specialty products at $378 million. Specifically, blueberries had the highest value per harvested acre in 2011 at $17,429, followed by sweet cherries at $15,500. Apples had a value per harvested acre of $12,542.

According to the Washington State Department of Agriculture, drought reduces crop production, sometimes for several years, reduces availability of food on rangeland for grazing animals and eliminates jobs in the field, at food processing plants and in affiliated facilities. Surprisingly, drought also reduces availability of relatively inexpensive hydropower for farmers, processors, and storage facilities, removing their competitive edge. Plus, drought increases shipping costs for some segments of the industry. For example, wheat growers may have to use truck and rail transport for a portion of their crop if the level of the Snake and Columbia Rivers become too low for barge traffic. Sixty percent of Washington wheat moves down these rivers.

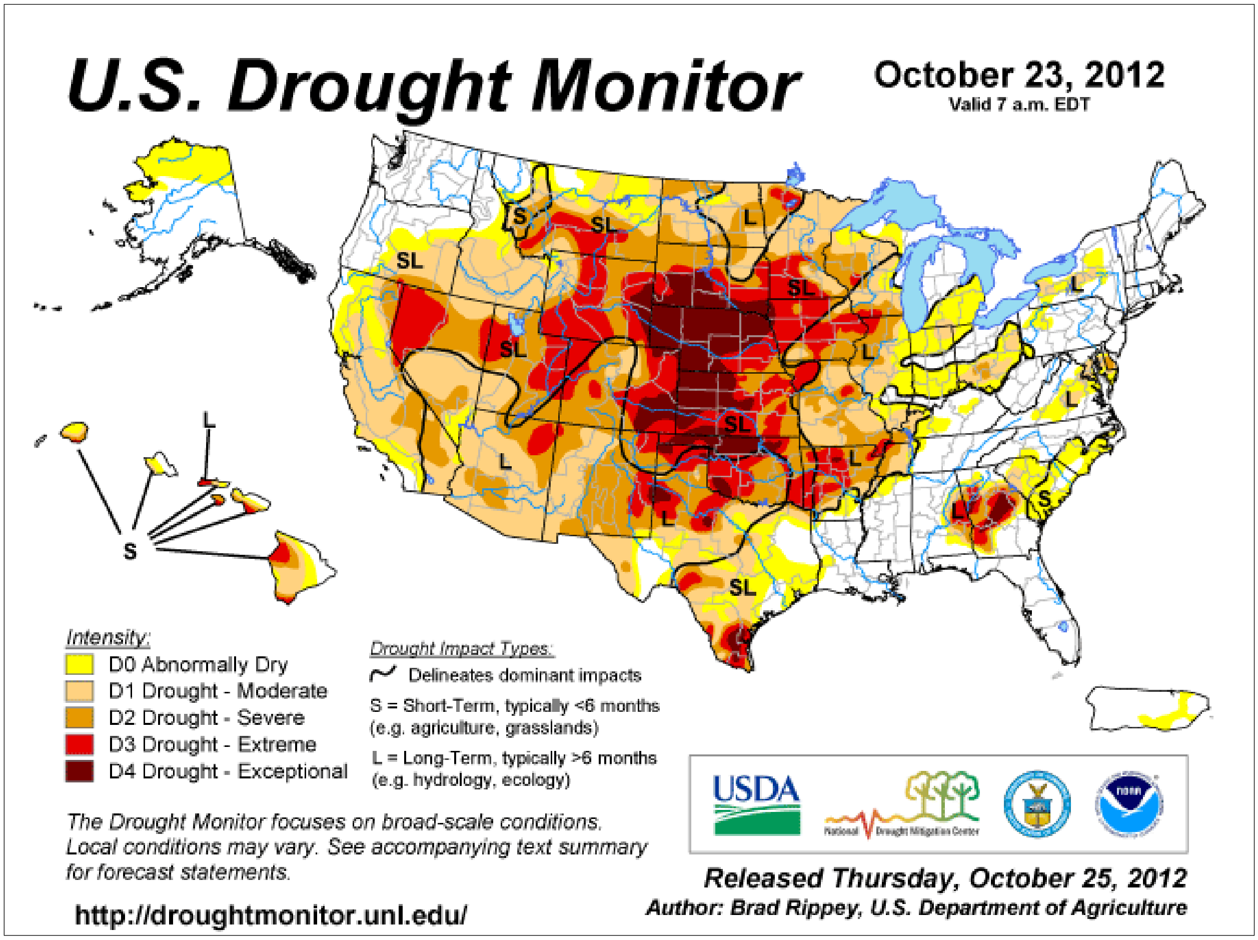
The impact of drought varies by region, by crop, and by the status of the irrigation water right holder (junior or senior). Loss of water is far more damaging to perennial crops, such as fruit trees, grapes, hops, and asparagus, than to annual crops because it takes perennials a number of years to return to normal production.

Jurisdictions Most Vulnerable to Drought[53]

Vulnerability to drought is affected by (among other things) population growth and shifts, urbanization, demographics, technology, water use trends, government policy, social behavior, environmental awareness, and economic ability to endure a drought. These factors evolve, and a community's vulnerability to drought may rise or fall in response to these changes. For example, increasing and shifting populations put greater pressure on water and other natural resources – more people need more water.

According to the National Drought Mitigation Center at the University of Nebraska-Lincoln, the Pacific Northwest region (Columbia, Willamette, and Snake River basins of Idaho, Oregon, and Washington, and portions of Montana and Wyoming) experienced drought more frequently than most other regions of the nation. The Palmer Drought Severity Index, a measure of moisture supply, is used to determine drought conditions. Figures produced by the National Drought Mitigation Center show that the Pacific Northwest had 10 percent or more of its area in severe or extreme drought during 61 years of the 100-year period of 1895-1995. Only the Missouri basin of the north-central United States and the Great Basin of Nevada and Utah had more years with 10 percent or more of its area experiencing severe or extreme drought, 70 years and 65 years, respectively. Furthermore, only two other regions had a third of their areas in drought more often than the Pacific Northwest – the Great Basin (37 years) and the Upper Colorado (34 years). The Missouri basin also was in this condition 33 years out of the 100-year period. The continental United States is broken into eighteen basins for drought study.

Figure 27 U.S. Drought Monitor



During 1895-1995, much of the state was in severe or extreme drought at least 5 percent of the time. All of Eastern Washington, except for the Cascade Mountain's eastern foothills, was in severe or extreme drought 10 to 15 percent of the time. The east slopes of the Cascades and much of Western Washington was in severe or extreme drought from 5 to 10 percent of the time.

For the State Hazard Mitigation Plan, a county is most vulnerable to drought if it meets at least five of the following seven criteria:

History of severe or extreme drought conditions:

The county must have been in serious or extreme drought at least 10-15 percent of the time from 1895 to 1995.

Demand on water resources based on:

Acreage of irrigated cropland. The acreage of the county's irrigated cropland must be in top 20 in the state.

Percentage of harvested cropland that is irrigated. The percentage of the county's harvested cropland that is irrigated must be in top 20 in the state.

Value of agricultural products. The value of the county's crops must be in the top 20 in the state.

Population growth greater than the state average. The county's population growth in 2000-2006 must be greater than state average of 8.17 percent.

A county's inability to endure the economic conditions of a drought is based on whether the county's median household income is less than 75 percent of the state median income of $51,749 in 2005.

The county classified as economically distressed in 2005 because its unemployment rate was 20 percent greater than the state average from January 2002 through December 2004.

The following nine counties meet the above criteria: Adams, Benton, Chelan, Franklin, Grant, Kittitas, Klickitat, Okanogan, and Yakima.

Figure 28 Washington State Counties Most At-Risk to Drought

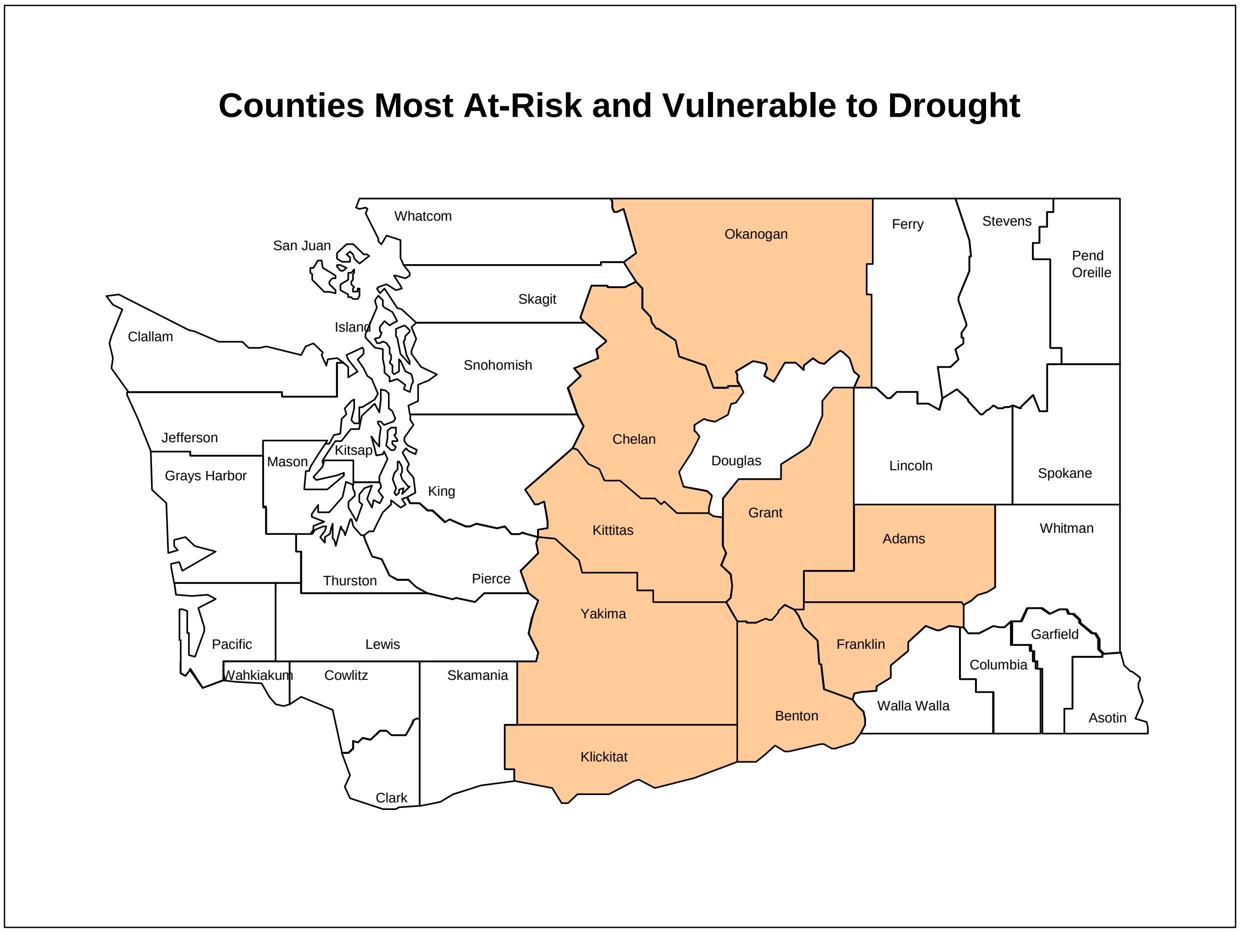


Table 20. County Median Household Income, County Unemployment Rates, County Market Value of Crops, County Population Growth and Time in Drought. The nine counties most vulnerable to drought are highlighted in yellow.

County	2011 Projected Median Household Income, dollars	Median Household Income ≤ 75% of State Average or $41,625	2012 Unemployed Rate, Percent	economically distressed unemployment rates ≥ 120% of state average or 9.24%	Market value of crops 2011	Census 1990	Census 2000	Census 2010	1990 to 2000 Percent Pop Growth	2000 to 2010 Percent Pop Growth	% Time in Drought 1985 - 1995
Washington	55,500		7.7%			4,866,663	5,894,143	6,724,540	21.1	14.1	5-10%
Adams	41,068	■	7.0		$344M	13,603	16,428	18,728	20.8	14.0	20-30%
Asotin	40,171	■	7.0		$13M	17,605	20,551	21,623	16.7	5.2	20-30%
Benton	60,608		8.1		$526M	112,560	142,475	175,177	26.6	23.0	> 30%
Chelan	46,275		6.3		$209M	52,250	66,616	72,453	27.5	8.8	> 30%
Clallam	38,886	■	9.1		$11M	56,204	64,179	71,404	14.2	11.3	
Clark	54,951		8.3		$53M	238,053	345,238	425,363	45.0	23.2	
Columbia	38,916	■	9.3	■	$40M	4,024	4,064	4,078	1.0	0.3	20-30%
Cowlitz	41,406	■	10.6	■	$26M	82,119	92,948	102,410	13.2	10.2	> 30%
Douglas	46,723		6.2		$193M	26,205	32,603	38,431	24.4	17.9	5-10%
Ferry	36,921	■	12.0	■	$3M	6,295	7,260	7,551	15.3	4.0	20-30%
Franklin	53,644		7.8		$467M	37,473	49,347	78,163	31.7	58.4	20-30%
Garfield	44,608		6.6		$26M	2,248	2,397	2,266	6.6	-5.5	> 30%
Grant	42,994		7.7		$1,190 M	54,798	74,698	89,120	36.3	19.3	> 30%
Grays Harbor	39,836	■	12.0	■	$33M	64,175	67,194	72,797	4.7	8.3	
Island	54,206		7.8		$14M	60,195	71,558	78,506	18.9	9.7	
Jefferson	44,348		9.0		$9M	20,406	26,299	29,872	28.9	13.6	
King	66,294		6.9		$127M	1,507,305	1,737,046	1,931,249	15.2	11.2	

Table 20. County Median Household Income, County Unemployment Rates, County Market Value of Crops, County Population Growth and Time in Drought. The nine counties most vulnerable to drought are highlighted in yellow.

Kitsap	55,400		7.1		$7M	189,731	231,969	251,133	22.3	8.3	
Kittitas	41,601	■	7.5		$61M	26,725	33,362	40,915	24.8	22.6	> 30%
Klickitat	43,104		8.0		$57M	16,616	19,161	20,318	15.3	6.0	> 30%
Lewis	38,325	■	11.8	■	$110M	59,358	68,600	75,455	15.6	10.0	
Lincoln	43,936		6.7		$126M	8,864	10,184	10,570	14.9	3.8	20-30%
Mason	47,724		10.2	■	$37M	38,341	49,405	60,699	28.9	22.9	
Okanogan	35,161	■	7.4		$209M	33,350	39,564	41,120	18.6	3.9	> 30%
Pacific	37,420	■	10.6	■	$35M	18,882	20,984	20,920	11.1	-0.3	
Pend Oreille	37,234	■	10.3	■	$3M	8,915	11,732	13,001	31.6	10.8	5-10%
Pierce	56,114		8.5		$83M	586,203	700,818	795,225	19.6	13.5	
San Juan	53,916		5.3		$4M	10,035	14,077	15,769	40.3	12.0	
Skagit	55,085		8.5		$256M	79,545	102,979	116,901	29.5	13.5	
Skamania	51,223		8.6		$3M	8,289	9,872	11,066	19.1	12.1	
Snohomish	62,687		7.4		$126M	465,628	606,024	713,335	30.2	17.7	
Spokane	46,846		8.2		$117M	361,333	417,939	471,221	15.7	12.7	20-30%
Stevens	40,282	■	10.6		$25M	30,948	40,066	43,531	29.5	8.6	5-10%
Thurston	60,621		7.4		$118M	161,238	207,355	252,264	28.6	21.7	
Wahkiakum	45,083		11.5		$3M	3,327	3,824	3,978	14.9	4.0	
Walla Walla	44,606		6.4		$344M	48,439	55,180	58,781	13.9	6.5	20-30%
Whatcom	49,775		7.0		$326M	127,780	166,826	201,140	30.6	20.6	
Whitman	31,396	■	6.2		$254M	38,775	40,740	44,776	5.1	9.9	20-30%
Yakima	41,164	■	8.2		$1,200M	188,823	222,581	243,231	17.9	9.3	> 30%
Washington	55,500		7.7%			4,866,663	5,894,143	6,724,540	21.1	14.1	5-10%

Source: Office Financial Management, OFM Census 2010 Data Products, http://ofm.wa.gov/pop/census2010/default.asp#summary accessed 25 October 25, 2012 and National Drought Mitigation Center, http://drought.unl.edu/; OFM Median Household Income, Updated October 25, 2011. Accessed 25 October

Table 20. County Median Household Income, County Unemployment Rates, County Market Value of Crops, County Population Growth and Time in Drought. The nine counties most vulnerable to drought are highlighted in yellow.
2012. http://www.ofm.wa.gov/economy/hhinc/; Source: ESD Map of County Unemployment Rates, Accessed 25 October 2012, https://fortress.wa.gov/esd/employmentdata/reports-publications/economic-reports/monthly-employment-report/map-of-county-unemployment-rates; Agriculture-A Cornerstone of Washington's Economy, Accessed 29 October 2012, http://agr.wa.gov/AgInWa/docs/126-CropProductionMap11-11.pdf

Potential Climate Change Impacts[54,55]

Washington State is particularly vulnerable to a warming climate: especially our snow-fed water supplies that provide our drinking water, irrigation for agriculture and nearly three-fourths of the electrical power we produce. Close to 40 communities including some of the state's largest population centers along our 2,300 miles of shoreline are threatened by rising sea levels. Ocean acidification, which is created when carbon dioxide reacts with seawater and reduces the water's pH, threatens our abundant shellfish.

According to a 2005 Governor's report prepared by the Climate Impacts Group titled *Uncertain Future: Climate Change and its Effects on Puget Sound*, from "paleoclimatological evidence, we know that over the history of the earth high levels of greenhouse gas concentrations have correlated with, and to a large extent caused, significant warming to occur, with impacts generated on a global scale." While the report also indicates that the "ultimate impact of climate change on any individual species or ecosystem cannot be predicted with precision," there is no doubt that Washington's climate has demonstrated change.

In July 2007, the Climate Impacts Group launched an unprecedented assessment of climate change impacts on Washington State. *The Washington Climate Change Impacts Assessment* (WACCIA) involved developing updated climate change scenarios for Washington State and using these scenarios to assess the impacts of climate change on the following sectors: agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon, and urban stormwater infrastructure. The assessment was funded by the Washington State Legislature through House Bill 1303.

In 2009, the Washington State Legislature approved the *State Agency Climate Leadership Act* Senate Bill 5560. The Act committed state agencies to lead by example in reducing their greenhouse gas (GHG) emissions to: 15 percent below 2005 levels by 2020; 36 percent below 2005 by 2035; and 57.5 percent below 2005 levels (or 70 percent below the expected state government emissions that year, whichever amount is greater.). The Act, codified in RCW 70.235.050-070, directed agencies to annually measure their greenhouse gas emissions, estimate future emissions, track actions taken to reduce emissions, and develop a strategy to meet the reduction targets. Starting in 2012 and every two years thereafter, each state agency is required to report to Washington State Department of Ecology the actions taken to meet the emission reduction targets under the strategy for the preceding biennium.

Recognizing Washington's vulnerability to climate impacts, the Legislature and Governor Chris Gregoire directed state agencies to develop an integrated climate change response strategy to help state, tribal and local governments, public and private organizations, businesses and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy*.

Over the next 50 - 100 years, the potential exists for significant climate change impacts on Washington's coastal communities, forests, fisheries, agriculture, human health, and natural disasters. These impacts could potentially include increased annual temperatures, rising sea level, increased sea surface temperatures, more intense storms, and changes in precipitation patterns. Therefore, climate change has the potential to impact the occurrence and intensity of natural disasters, potentially leading to additional loss of life and significant economic losses.

Multiple droughts since 1971 have resulted in dry streams, withered and abandoned crops, dead fish, record low rivers, declining ground water levels, more forest fires, less summer water for farms, cities and forests plus less water for city municipal water sources affecting industries, businesses and homeowners. Between 2000 and 2005, Washington experienced two drought emergencies, resulting in drought declarations by Governors Locke and Gregoire.

The Yakima River Basin produces crops worth about $1 billion annually, mostly from perennial crops. Many of the Yakima Basin perennial crop growers face water shortages. In the low water year of 2001, reduced water allocation resulted in economic losses of $140 - $195 million. High river flows occurring earlier in the year will result in a 20-40% reduction in water availability by 2050. One potential solution is more reservoir storage, but this is expensive: the proposed Black Rock Reservoir would cost $3.5 to $4 billion.

Federal and state costs of fighting wildfires may exceed $75 million per year by the 2020's which is 50% higher than current expenditures. Economic impacts from fires include: lost timber value, lost recreational expenditures, human health costs, and air pollution and habitat loss.

With a warming climate, the growing season for some plants may be extended. The last frost would come earlier in the spring and first frost would come later in the fall. However, this advantage can be erased if there is limited water to nourish forests and crops during hot weather. Studies in Washington wine country conclude that more frequent series of extreme hot or cold days can result in damage and loss, even if the rest of the season is more moderate. Warmer winters allow forest and crop pests to reproduce longer and suffer less winter die offs, so pest populations can boom. This is already happening in Canada and even northeast Washington forests where pine bark beetles are rapidly devastating large tracts of forests.

Ecosystem changes from shifting seasons can:

- break historic linkages between predator and prey migrations
- shift timing of bloom times and necessary pollinators
- cause population booms or crashes that affect the rest of the system
- allow invasive plants, animals and insects to move into new territory
- stress native species with unusual weather and water conditions

At Risk State Facilities for Drought

This profile will not attempt to estimate potential losses to state facilities due to drought. This hazard poses little threat to people and the built environment, but can pose significant damage to the state's economy.

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Earthquake

	Frequency	50+ yrs	10-50 yrs	1-10 yrs	Annually
	People	<1,000	1,000-10,000	10,000-50,000	50,000+
	Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
	Environment	<10%	10-15%	15%-20%	20%+
	Property	<$100M	$100M-$500M	$500M-$1B	$1B+
Earthquake	**Hazard scale**	< Low to High >			

Risk Level

Frequency – According to Washington State Department of Natural Resources, over 1,000 earthquakes occur annually in the state. This is an average of approximately 3 per day though most go unfelt and do not cause damage.[56] Larger magnitude earthquakes, which result in damage, occur less frequently in the state.

People – The population affected in an earthquake depends on many variables like the magnitude of the earthquake, the population present in the areas of strongest shaking, the time of day, the age of buildings affected, soil at the location, and many other factors. It is plausible that an earthquake in the state could injure or kill anywhere between 0 and 10,000 or more people.

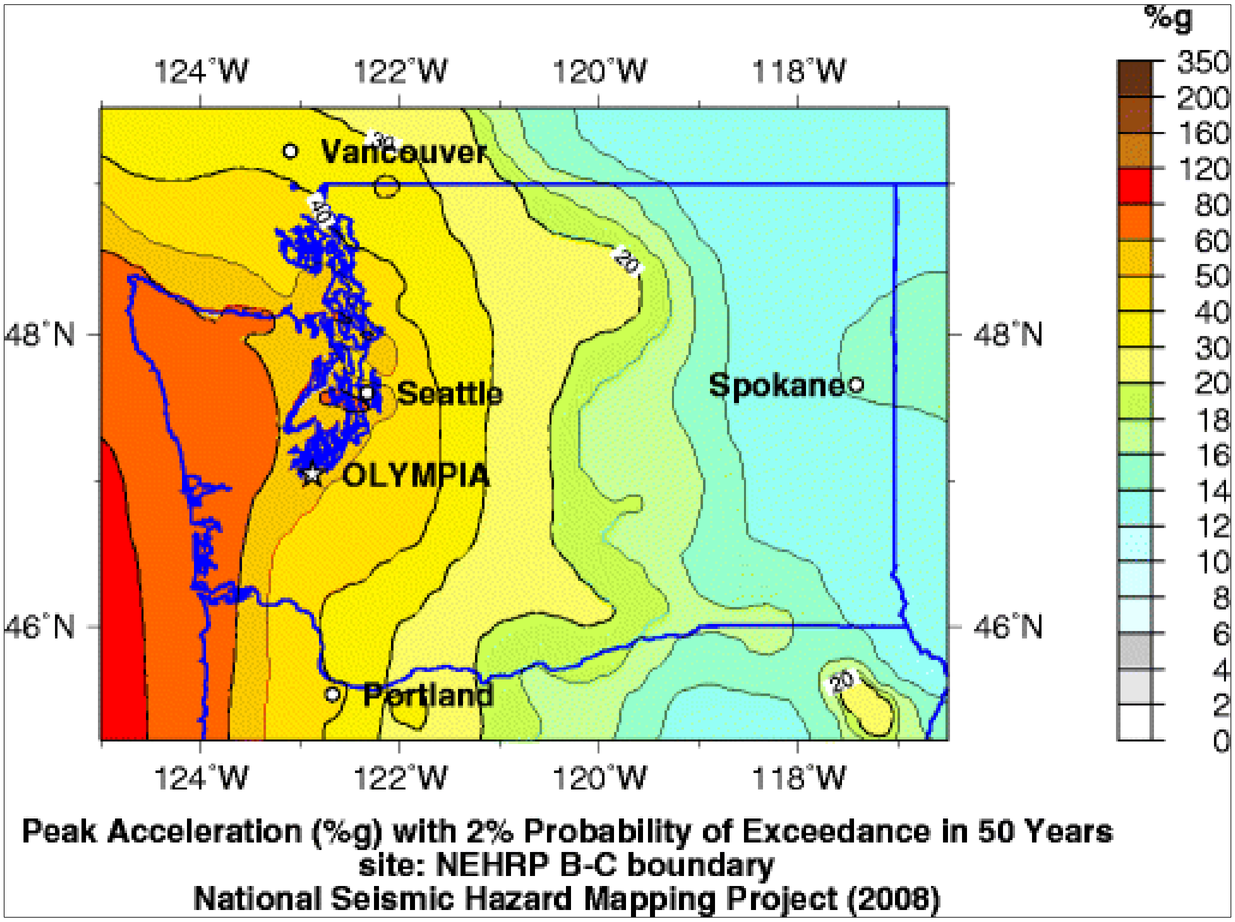
Economy – The economy affected by an earthquake depends on variables similar to above and if there is a large magnitude earthquake near the major Puget Sound ports in Olympia, Seattle, Tacoma, and Everett could cause significant damage to the state's economy.

Environment – The type of environmental impact or damage that occurs in the event of an earthquake does not meet the minimum threshold of ten percent or more loss of a single species or habitat.

Property – Statewide annualized loss estimates from Hazus-MH 2.1 indicate total losses over $300,000 million. Property damage could be in excess of $20 billion dollars in the event of a catastrophic earthquake.

HIVA Risk Classification for Earthquake is 1A (highest) or Mitigation to Reduce Risk is Required.

Figure 30 Hazard Area Map: The USGS map shows how the State's Peak Ground Acceleration (PGA) is much higher in the heavily populated and highly urbanized Puget Sound region than in other parts of the state.



Summary

The hazard – An earthquake is the sudden release of stored energy that produces a rapid displacement on a fault and radiates seismic waves. Although over a thousand earthquakes are recorded in Washington each year, only a few have shaking strong enough to be felt by people. Infrequent large earthquakes such as the 2001 Nisqually event produce very strong ground shaking. This strong shaking causes damage directly to structures and a variety of secondary effects such as ground failure, landslides, and liquefaction. Earthquakes also have a high potential for causalities given their sudden onset.

Previous occurrences – The Washington coast and the greater Puget Sound Basin are most at risk although damaging temblors have occurred east of the Cascades. The Puget Sound basin had damaging earthquakes in 1909, 1939, 1946, 1949, 1965, and 2001. Eastern Washington had a large earthquake in 1872 near Lake Chelan and in 1936 near Walla Walla.

Probability of future events - Because of its location near the collision boundary of two major tectonic plates, Washington State is particularly vulnerable to a variety of earthquakes. FEMA has determined that Washington State ranks second (behind only California) among states most susceptible to damaging earthquakes in terms of economic loss. FEMA notes that a majority of the state is at risk to strong shaking (on a scale of minimal to strong) with shaking magnitude generally decreasing from west to east.

Jurisdictions at greatest risk – Communities in western Washington, particularly those in the Puget Sound Basin and along the Pacific coast, are most at risk from earthquakes. Some counties in eastern Washington (Chelan, Douglas, Grant, Kittitas, Yakima, Benton, Franklin, Walla Walla, and Spokane) are also vulnerable.

The table below uses United States Geological Service data and Hazus-MH to model several scenarios completed throughout the state.

Table 21. The Washington State Earthquake Hazards Scenario Catalog.

Scenario	Fault	Magnitude (M)	Total Fatalities (2PM)	Total Injuries (Severity 1, 2 3) at 2PM	Total Number of Buildings Extensively Damaged	Total Number of Buildings Completely Damaged	Displaced Households	People Requiring Shelter (Individuals)	Capital Stock Losses in Millions	Debris Total in Millions of Tons	Truckloads of Debris (25 Tons Per Truckload)	People Without Power (Day 1)	People Without Potable Water (Day 1)
Boulder Creek	Boulder Creek fault	6.8	0	15	77	1	9	6	$106	0.02	800,000	0	0
Canyon River/Price Lake	Canyon River - Price Lake fault	7.4	0	117	511	26	49	32	$719	0.12	4,760,000	166	1,185
Cascadia Subduction Zone	CSZ Megathrust	9.0	288	7,246	43,681	8,768	18,385	11,630	$11,994	5.68	227,240,000	2,017	131,035
Cascadia Subduction Zone - North	CSZ Megathrust - Northern Section	8.3	39	1,404	12,233	1,940	3,692	2,452	$2,708	1.40	55,920,000	0	2,858
Chelan	Chelan Fault	7.2	0	31	375	11	33	25	$151	0.05	1,880,000	0	466
Cle Elum	Cle Elum-Wallula Deformed Zone	6.8	1	54	550	75	138	110	$215	0.07	2,600,000	1,516	1,058
Devils Mountain - Utsalady Point	Devils Mtn. Fault	7.0	35	617	2,645	764	880	1,197	$1,137	0.37	14,720,000	1,196	879
Devils Mountain - West	Devils Mtn. Fault - Western Section	7.4	61	1,058	4,864	1,439	1,971	1,448	$1,866	0.65	25,920,000	10,176	29,697
Hite	Hite Fault	6.8	52	743	2,700	1,354	1,321	1,011	$856	0.49	19,480,000	1,743	19,321
Lake Creek Boundary Creek	Little River Fault	6.8	13	240	1,612	407	460	283	$518	0.19	7,680,000	9,095	544
Mill Creek Thrust/Toppenish Ridge	Toppenish Ridge Fault	7.0	6	185	1,678	297	287	325	$339	0.17	6,880,000	1,135	9,440
Olympia\Nisqually	Nisqually Intraslab (52 km depth)	7.2	37	1,713	6,026	547	3,258	2,015	$5,325	1.43	57,040,000	0	45,916
Olympia Aftershock	Olympia Fault	5.7	1	93	388	29	242	139	$426	0.09	3,480,000	0	274
Saddle Mountain-Hanford	Saddle Mountains Fault	7.4	9	269	2,520	832	405	396	$590	0.27	10,760,000	4,382	1,533
Sea-Tac	Sea-Tac Intraslab (52 km depth)	7.2	117	3,404	8,801	1,123	6,489	3,871	$8,241	2.36	94,480,000	0	132,577
Seattle	Seattle Fault	7.2	1,049	16,628	29,094	9,062	31,278	18,193	$19,868	7.42	296,720,000	265,583	399,991
Southern Whidbey Island Fault Zone (SWIF)	Southern Whidbey Island Fault Zone	7.4	432	7,361	17,502	6,258	13,948	8,106	$10,315	3.57	142,960,000	115,230	188,457
Spokane	Blind Fault	5.5	0	34	36	0	23	16	$361	0.04	1,560,000	0	0
St. Helens Zone	St. Helens Deformed Zone	7.0	0	25	119	1	10	7	$162	0.03	1,120,000	0	0
Tacoma	Tacoma Fault	7.0	328	5,742	15,410	4,457	11,576	7,146	$8,654	2.95	117,960,000	87,675	193,544

* Ground motions with peak horizontal ground acceleration (PGA) exceeding 0.02 g
** Counties just in Washington State. Does not include losses due to tsunami

Source: https://fortress.wa.gov/dnr/seismicscenarios/

The Earthquake Hazard[57, 58,59]

An earthquake is the sudden release of stored energy that produces a rapid displacement on a fault and radiates seismic waves. Earthquakes in Washington, and throughout the world, occur predominantly because of plate tectonics - the relative movement of plates of oceanic and continental rocks that make up the rocky surface of the earth. Earthquakes can also occur because of volcanic activity and other geological processes. With plate tectonics, accumulated stress is released as a result of the rupture of rocks along opposing fault planes in the Earth's outer crust. These fault planes are typically found along borders of the Earth's 10 tectonic plates (including the Juan De Fuca Plate impacting the Northwestern United States. Faults are arbitrary mapped and can be viewed in Figure 5.4-2 and Figure 5.4-3. The areas of greatest tectonic instability occur at the perimeters of the slowly moving plates, as these locations are subjected to the greatest strains from plates traveling in opposite directions and at different speeds. Deformation along plate boundaries causes strain in the rock and the consequent buildup of stored energy. When the built-up stress exceeds the rocks' strength, a rupture occurs. The rock on both sides of the fracture is snapped, releasing the stored energy and producing seismic waves, generating an earthquake.

Figure 31: Tectonic Plates of the World[60]

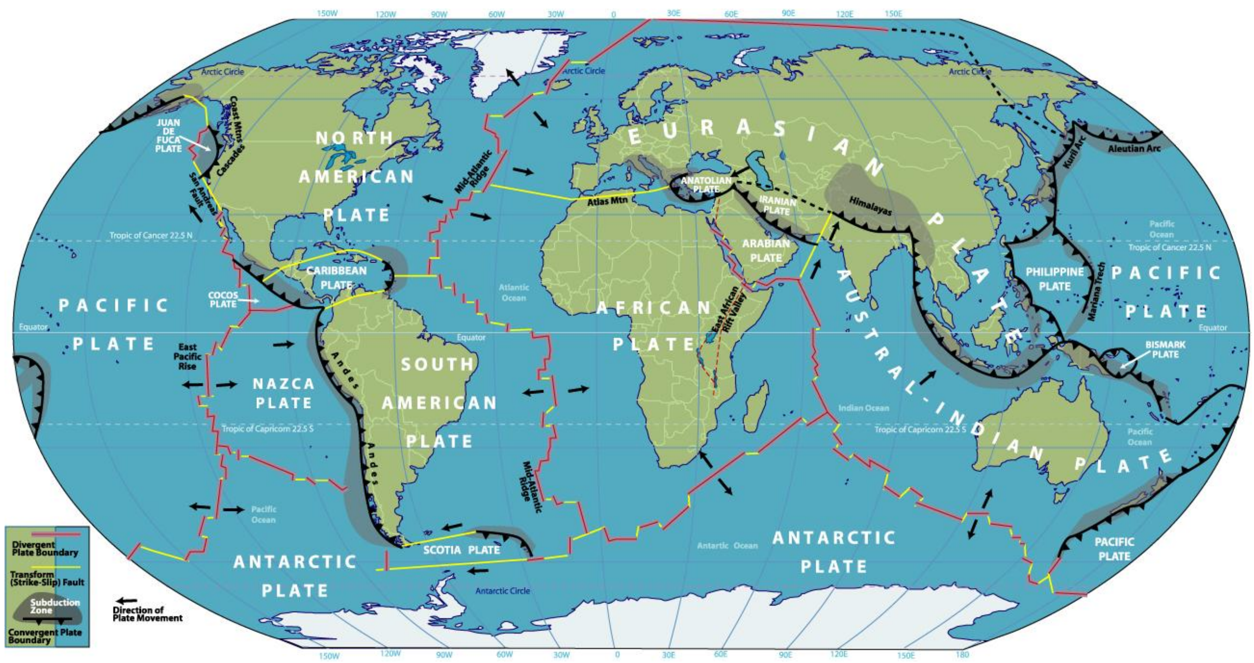
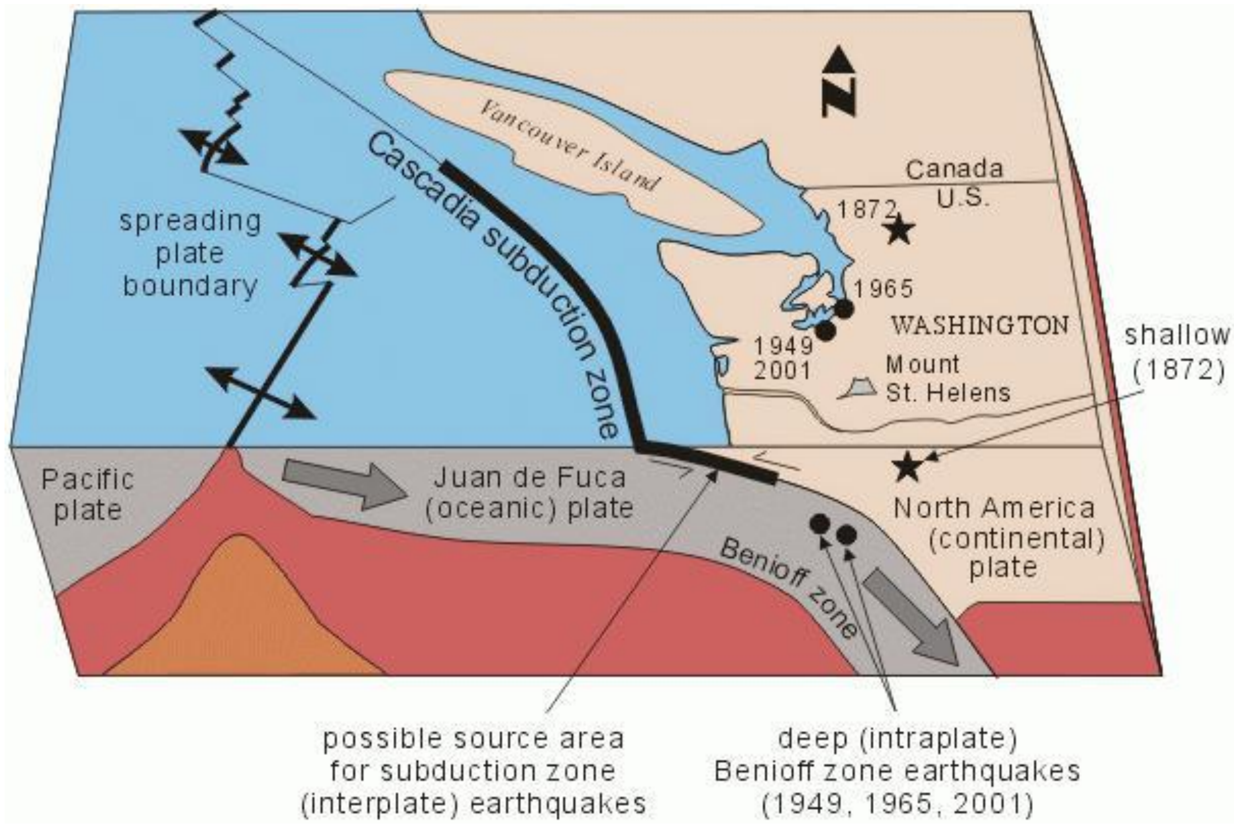


Figure 32: Cascadia Subduction Zone[61]



Earthquakes are measured in terms of their magnitude and intensity. Magnitude (M) is a measure of the total energy released by an earthquake, and intensity refers to the shaking an earthquake produces. The most common magnitude measure used is the "moment magnitude" which is calculated by seismologists from the amount of slip (movement) on the fault causing the earthquake and the area of the fault surface that ruptures during the earthquake. Moment magnitudes are similar to the Richter magnitude, which was used for many decades but has now been replaced by the moment magnitude. Beginning in 2002, the USGS began using Moment Magnitude as the preferred measure of magnitude for all USGS earthquakes greater than magnitude 3.5. This was primarily due to the fact the Richter scale has an upper bound, so large earthquakes were difficult to measure.

The magnitudes for the largest earthquakes recorded worldwide and in Washington are shown in Table 5.4-2 below.

Table 22 Largest Recorded Earthquakes in the World and Washington[62, 63]

Worldwide	Magnitude	Washington	Magnitude
1960 Chile	9.5	1872 Chelan	6.8[a]
1964 Prince William Sound, Alaska	9.2	1949 Olympia	6.8
2004 Sumatra, Indonesia	9.1	2001 Nisqually	6.8
2011 Japan	9.0	1965 Tacoma	6.7
1952 Kamchatka, Russia	9.0	1939 Bremerton	6.2
2010 Chile	8.8	1936 Walla Walla	6.1
1906 Ecuador	8.8	1909 Friday Harbor	6.0

[a] Estimated magnitude.

In evaluating earthquakes, it is important to recognize that the earthquake moment magnitude scale is not linear, but rather logarithmic. Each one step increase in magnitude, for example from M7 to M8, corresponds to an increase of about a factor of 30 in the amount of energy released by the earthquake, because of the mathematics of the magnitude scale.

Thus, a M7 earthquake releases about 30 times more energy than a M6, while a M8 releases about 30 times more energy than a M7 and so on. Thus, a great M9 earthquake releases nearly 1,000 times more energy than a large earthquake of M7 and nearly 30,000 times more energy than a M6 earthquake.

The public often assumes that the larger the magnitude of an earthquake, the “worse” it is. That is, the “big one” is the M9 earthquake and smaller earthquakes such as M6 or M7 are not the “big one”. However, this is true only in very general terms. Higher magnitude earthquakes do affect larger geographic areas, with much more widespread damage than smaller magnitude earthquakes. However, for a given site, the magnitude of an earthquake is <u>not</u> a good measure of the severity of the earthquake at that site. Instead, severity can measured by ground shaking, or the intensity of the earthquake.

For any earthquake, the intensity of ground shaking at a given site depends on four main factors:

- Earthquake magnitude,
- Earthquake epicenter, which is the location on the earth’s surface directly above the point of origin of an earthquake,
- Earthquake depth, and
- Soil or rock conditions at the site, which may amplify or deamplify earthquake ground motions

An earthquake will generally produce the strongest ground motions near the epicenter (the point on the ground above where the earthquake initiated) with the intensity of ground motions diminishing with increasing distance from the epicenter. The intensity of ground shaking at a given location depends on the four factors listed above. Thus, for any given earthquake there will be contours of varying intensity of ground shaking vs. distance from the epicenter. The intensity will generally decrease with distance from the epicenter, and often in an irregular pattern, not simply in concentric circles. This irregularity is caused by soil conditions, the complexity of earthquake fault rupture patterns, and possible directionality in the dispersion of earthquake energy.

The amount of earthquake damage and the size of the geographic area affected generally increase with earthquake magnitude:

- Earthquakes below about M5 are not likely to cause significant damage, even locally very near the epicenter.
- Earthquakes between about M5 and M6 are likely to cause moderate damage near the epicenter.
- Earthquakes of about M6.5 or greater (e.g., the 2001 Nisqually earthquake in Washington) can cause major damage, with damage usually concentrated fairly near the epicenter.
- Larger earthquakes of M7+ cause damage over increasingly wider geographic areas with the potential for very high levels of damage near the epicenter.
- Great earthquakes with M8+ can cause major damage over wide geographic areas.
- A mega-quake M9 earthquake on the Cascadia Subduction Zone could affect the entire Pacific Northwest from British Columbia, through Washington and Oregon, and as far south as Northern California, with the highest levels of damage nearest the coast.

There are many measures of the severity or intensity of earthquake ground motions. The Modified Mercalli Intensity scale (MMI) was widely used beginning in the early 1900s. MMI is a descriptive, qualitative scale that relates severity of ground motions to the types of damage experienced. MMIs range from I to XII. More accurate, quantitative measures of the intensity of ground shaking have largely replaced the MMI and these are used in this mitigation plan.

Modern intensity scales use terms that can be physically measured with seismometers, such as the acceleration, velocity, or displacement (movement) of the ground. The intensity of earthquake ground motions may also be measured in spectral terms, as a function of the frequency of earthquake waves propagating through the earth. In the same sense that sound waves contain a mix of low-, moderate- and high-frequency sound waves, earthquake waves contain ground motions of various frequencies. The behavior of buildings and other structures depends substantially on the vibration frequencies of the building or structure vs. the spectral (frequency) content of earthquake waves. Earthquake ground motions also include both horizontal and vertical components.

A common physical measure of the intensity of earthquake ground shaking, and the one used in this mitigation plan, is Peak Ground Acceleration (PGA). PGA is a measure of the intensity of shaking, relative to the acceleration of gravity (g). For example, an acceleration of 1.0 g PGA is an extremely strong ground motion, which does occur near the epicenter of large earthquakes. With a vertical acceleration of 1.0 g, objects are thrown into the air. With a horizontal acceleration of 1.0 g, objects accelerate sideways at the same rate as if they had been dropped from the ceiling. 10% g PGA means that the ground acceleration is 10% that of gravity, and so on.

Damage levels experienced in an earthquake vary with the intensity of ground shaking and with the seismic capacity of structures. The following generalized observations provide qualitative statements about the likely extent of damages for earthquakes with various levels of ground shaking (PGA) at a given site:

Ground motions of only 1% g or 2% g are widely felt by people; hanging plants and lamps swing strongly, but damage levels, if any, are usually very low.

Ground motions below about 10% g usually cause only slight damage.

Ground motions between about 10% g and 30% g may cause minor to moderate damage in well-designed buildings, with higher levels of damage in more vulnerable buildings. At this level of ground shaking, some poorly built buildings may be subject to collapse.

Ground motions above about 30% g may cause significant damage in well-designed buildings and very high levels of damage (including collapse) in poorly designed buildings.

Ground motions above about 50% g may cause significant damage in most buildings, even those designed to resist seismic forces.

The maps on the following pages show contours of Peak Ground Acceleration (PGA) with 10% and 2% chances of occurring over the next 50 years. Because the earthquake sources are not uniform, the earthquake threat in Washington is also not uniform. These maps are created with data from the United States Geological Survey (USGS) to produce uniform probabilistic seismic hazard maps for the United States. The ground shaking values on the maps are expressed as a percentage of g, the acceleration of gravity. For example, the 10% in 50 year PGA value means that over the next 50 years there is a 10% probability of this level of ground shaking or higher.

In very qualitative terms, the 10% in 50 year ground motion represents a likely earthquake while the 2% in 50 year ground motion represents a level of ground shaking close to but not the absolute worst case scenario.

A very important caveat for interpreting these maps is that the 2008 USGS seismic hazard maps show the level of ground motions for rock sites. Ground motions on soil sites, especially soft soil sites will be significantly higher than for rock sites. Thus, for earthquake hazard analysis at a given site it is essential to include consideration of the site's soil conditions.

Figure 33 on the following page, the statewide 2% in 50 year ground motion map, is the best statewide representation of the variation in the level of seismic hazard in Washington with location:
The dark red, pink and orange areas have the highest levels of seismic hazard.
The tan, yellow and blue areas have intermediate levels of seismic hazard.
The bright green and pale green areas have the lowest levels of seismic hazard.

The highest hazard is along the Washington coast—these areas are immediately above the Cascadia subduction zone (Figure 33). Moving inland, the contours bend inland around the greater Puget Sound area from about the Columbia River; this bending is largely due to the hazard from deep earthquakes like the 2001 Nisqually earthquake. Generally, the effect of crustal faults is muted because they are poorly defined; however, these earthquakes are the most damaging due to their proximity to the earth's surface. Two notable exceptions are the bubble of higher hazard (red color) over the Seattle fault and the southern Whidbey Island fault in Puget Sound. While most earthquakes occur in Western Washington, earthquake hazards are significant east of the Cascades to about the Columbia River. The green area to the west of the Columbia shows acceleration values comparable to those seen over portions of western Washington in the Nisqually earthquake.

The detailed geographical patterns in the maps reflect the varying contributions to seismic hazard from earthquakes on the Cascadia Subduction Zone and crustal earthquakes within the North American Plate. For example, the bands of dark red (high hazard) in the Puget Sound area shown in Figures 34 and 35 reflect areas with a moderately high earthquake hazard from Cascadia Subduction Zone earthquakes combined with a high hazard from the most active crustal faults in the Puget Sound Area – the Seattle Fault System and the Southern Whidbey Island Fault.

The differences in geographic pattern between the 2% in 50 year maps and the 10% in 50 year maps reflect different contributions from Cascadia Subduction Zone earthquakes and crustal earthquakes.

These maps are generated by including earthquakes from all known faults, taking into account the expected magnitudes and frequencies of earthquakes for each fault. The maps also include contributions from unknown faults, which are statistically possible anywhere in Washington. The contributions from unknown faults are included via "area" seismicity which is distributed throughout the state.

The current scientific understanding of earthquakes is incapable of predicting exactly where and when the next earthquake will occur. However, the long term probability of earthquakes is well enough understood to make useful estimates of the probability of various levels of earthquake ground motions at a given location.

The current consensus estimates for earthquake hazards in the United States are incorporated into the 2008 USGS National Seismic Hazard Maps. These maps are the basis of building code design requirements for new construction, per the International Building Code adopted in Washington. The earthquake ground motions used for building design are set at 2/3rds of the 2% in 50 years level of ground motion.

Figure 34 2008 USGS Seismic Hazard Map: Washington State PGA value (%g) with a 2% Chance of Exceedance in 50 years (source: http://earthquake.usgs.gov/earthquakes/states/washington/hazards.php)

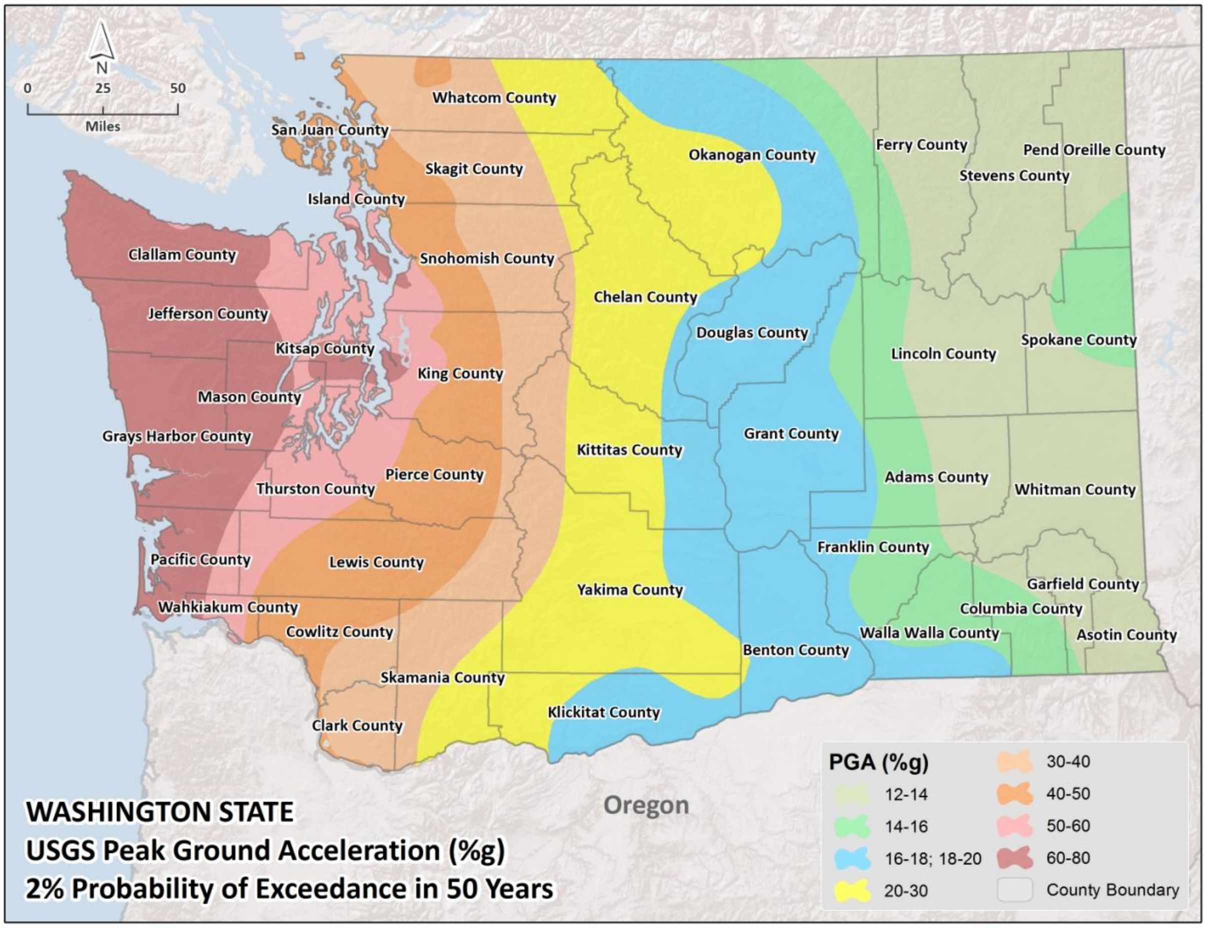
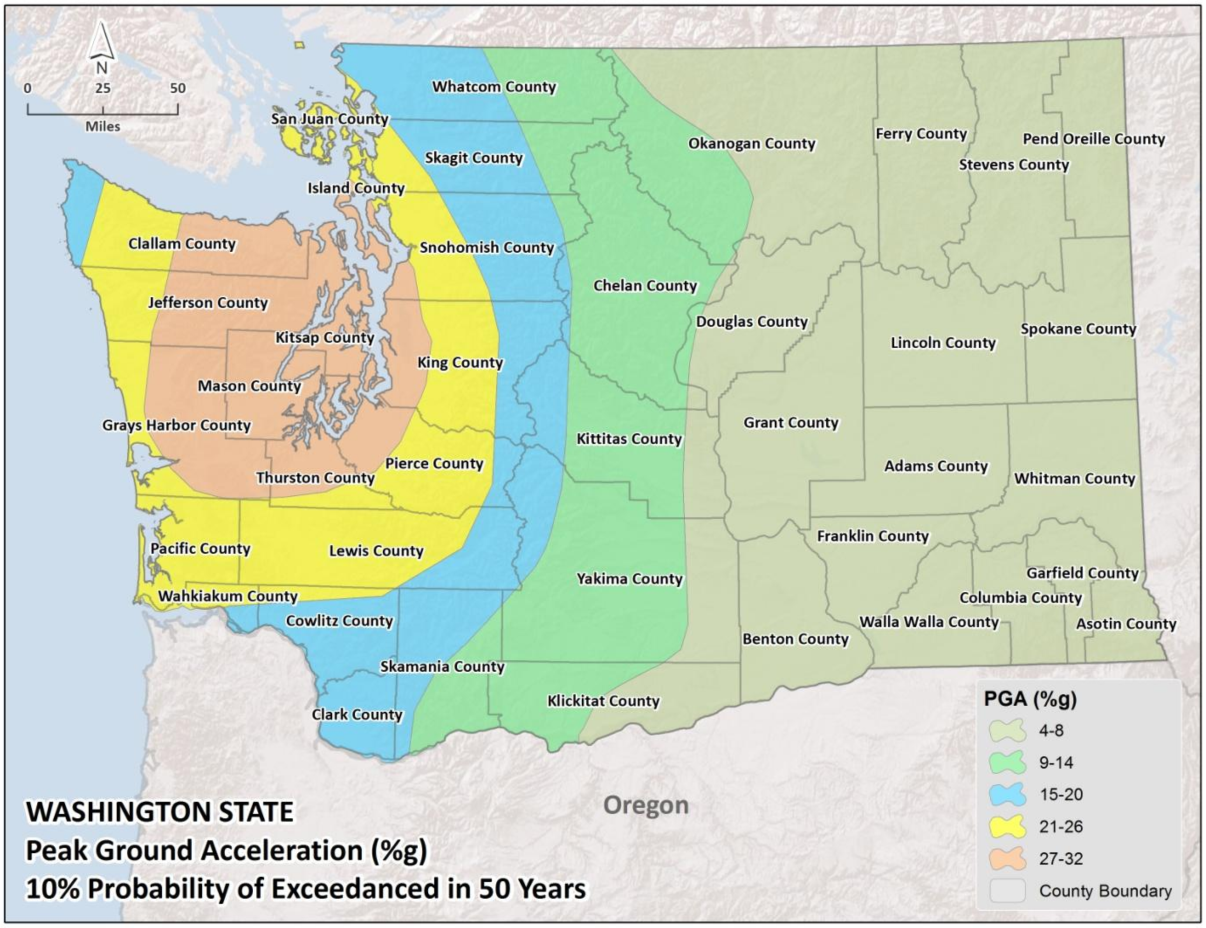


Figure 35 2008 USGS Seismic Hazard Map: Washington State PGA value (%g) with a 10% Chance of Exceedance in 50 years

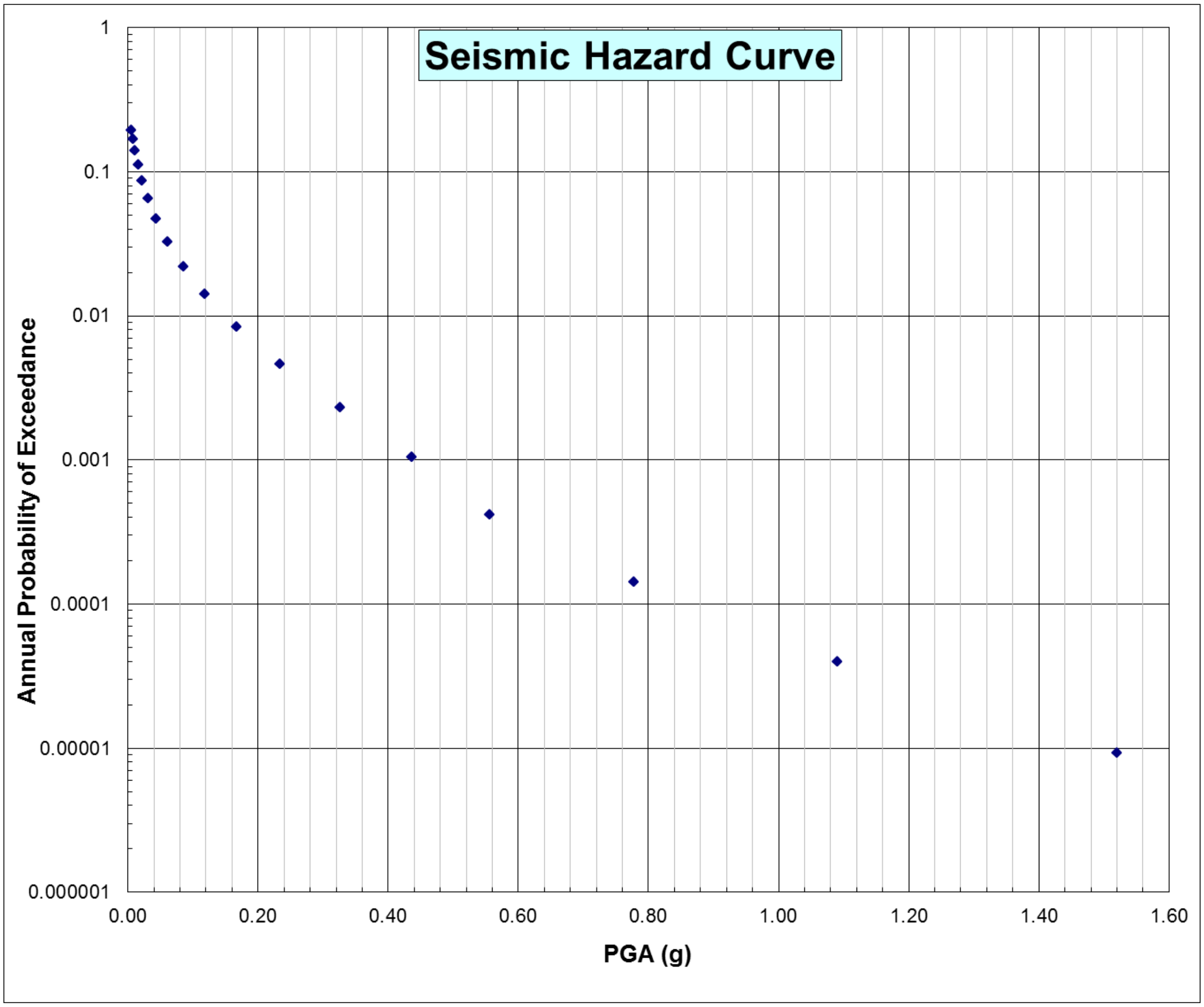


The ground motions shown in the previous figures represent ground motions with the specified probabilities of occurrence. At any given site, earthquakes may be experienced with ground motions over the entire range of levels of ground shaking from just detectible with sensitive seismometers to higher than the 2% in 50 year ground motion.

The complete probabilistic picture of earthquake ground motions at a given site is shown in a seismic hazard curve, which shows the annual probability of ground motions covering the full range of ground motions (Figure 5.4-6). For any site, the annual probability always decreases with increasing level of ground shaking (PGA).

However, as illustrated in the preceding figures, the levels of ground shaking vary markedly with location in Washington.

Figure 36 Seismic Hazard Curve Example



Although over one thousand earthquakes occur in Washington each year, most produce ground shaking that is too small to be felt. Occasionally large earthquakes produce very strong ground shaking. It is this strong shaking and its consequences – ground failure, landslides, liquefaction – that damages buildings and structures and upsets the regional economy.

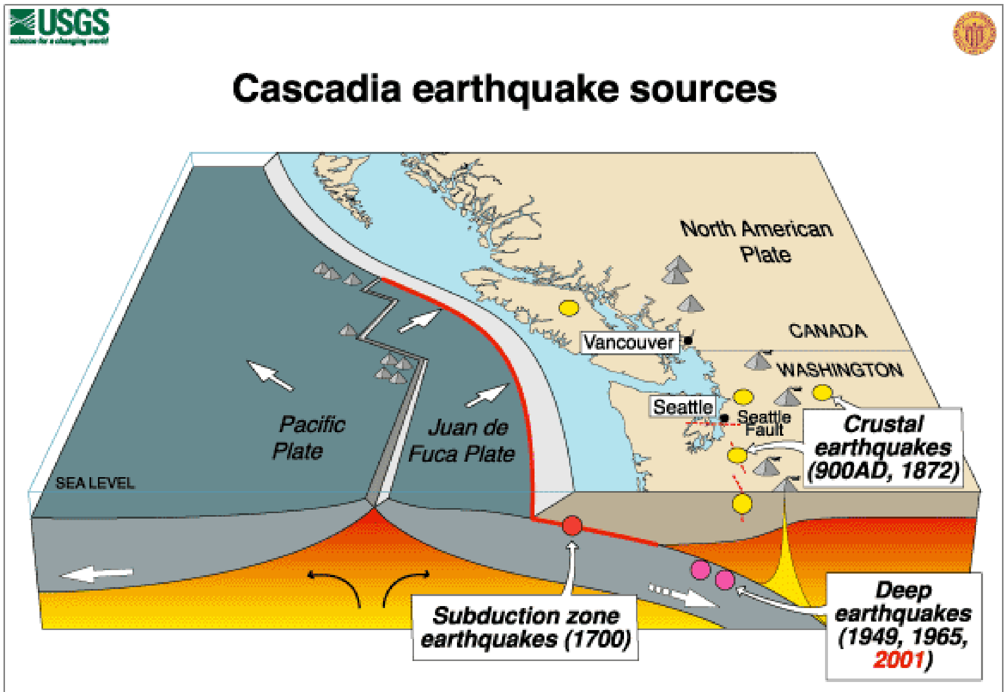
Washington's earthquake hazards reflect its tectonic setting. The Pacific Northwest is at a convergent margin between two tectonic plates of the Earth's crust. The Cascadia Subduction Zone (CSZ) is the long fault boundary between the continental North America plate and the oceanic Juan de Fuca plate that lies offshore from northern California to southern British Columbia. The two plates are converging at a rate of about 2 inches per year. The interaction between these two plates creates a complicated system of three distinct earthquake source zones. The earthquakes produced by each source zone are responsible for the earthquake hazards across Washington.

The first source zone is the Cascadia Subduction Zone; the long fault boundary between the North American and Juan de Fuca plate (see Figure 5.4-3 and Figure 5.4-7). This source zone produces great earthquakes, similar to the 2004 Indonesian earthquake, about every 500 years. Most of the fault area is offshore, so most of the ground shaking effects is expected in western Washington.

As the Juan de Fuca plate subducts (slides) beneath North America, the plate begins to bend more steeply into the earth. The area near this bend is the second source zone, usually called the deep (Benioff) zone. This is the most frequent source of damaging earthquakes for Puget Sound and the source of the 2001 Nisqually earthquake (This fault can be seen in see Figure 5.4-3).

The third zone is the earth's shallow crust and is the most poorly understood of the three source zones. Since 2000, geologists have discovered over 12 active crustal faults in Puget Sound, but new geologic assessments east of the Cascade Range indicate that the earthquake hazard in central and northeast Washington maybe greater than previously thought. This is a topic of active research within the scientific community. (Crustal faults can be seen in Figure 5.4-7.)

Figure 37. Earthquake source zones for Washington with maximum earthquake magnitude and estimated recurrence time.



Source	Affected area	Max. Size	Recurrence
Subduction Zone	W.WA, OR, CA	M 9	500-600 yr
Deep Juan de Fuca plate	W.WA, OR,	M 7+	30-50 yr
Crustal faults	WA, OR, CA	M 7+	Hundreds of yr?

Understanding local earthquake hazards requires understanding of how each of the three source zones will affect individual localities. West of the Cascade Mountains, all three source zones combine to determine local hazards. East of the Cascade Mountains will usually not be affected by ground shaking from deep earthquakes due to the manner in which seismic waves travel greater distances, and, therefore, most structures will likely show minimal effects from Cascadia ground shaking. However, certain large structures in eastern Washington, such as dams and bridges, may be vulnerable to very long period shaking expected from a Cascadia earthquake. Crustal (shallow) faults, which are closer to the surface, are located throughout the entire state, and can produce intense, localized ground shaking.

Although the probabilistic maps in Figure 5.4-4 and Figure 5.4-5 are the primary input to the International Building Code and the code governing highway construction, it is sometimes useful to consider the effects from an individual fault. This requires calculating "deterministic" ground motion models. For a deterministic model, seismologists calculate the expected ground shaking but do not consider how often the earthquake may occur. They pick reasonable faulting parameters and generally use a known fault. The USGS, Washington Department of Natural Resources, and Washington Emergency Management Division produced a series of 15 deterministic ground motion models (Table 5.4-3) for selected shallow faults, deep earthquakes, and the Cascadia subduction zone. Again, these deterministic models ignore the likelihood of an earthquake occurring, but focus on the shaking expected should such an event occur. While many of these scenario models are centered on known faults, some events have been developed for research purposes. Some of these ground motion models, called ShakeMaps, are available at http://earthquake.usgs.gov/eqcenter/shakemap/list.php?s=1&y=2009.[1]

Table 23: Deterministic Ground Motion Models (USGS ShakeMaps) for Selected Sources

Scenario	Magnitude	Basis	Source zone
Boulder Creek	6.8	Trenching	Crustal
Canyon River-Price Lake	7.4	Trenching	Crustal
Chelan	7.1	Scenario: Not on a known fault	Crustal
Cle Elum	6.8	Scenario: Not on a known fault	Crustal
Lake Creek fault	6.8	Trenching	Crustal
Mill Creek (Toppenish Ridge)	7.1	Scenario weakly based on trenching, known fault	Crustal
Saddle Mountains (eastern WA)	7.35	Trenching	Crustal
St. Helens Seismic zone	7.0	Seismicity	Crustal
Seattle fault	6.7	Trenching, uplift	Crustal
Southern Whidbey Island fault	7.4	Trenching, uplift	Crustal
Spokane	5.5	Seismicity, not on a known fault	Crustal
Tacoma	7.1	Trenching, uplift	Crustal
Cascadia	9.0	Paleoseismology	Subduction
Nisqually	7.2	Historical seismicity	Deep
Seattle-Tacoma	7.2	Historical seismicity	Deep

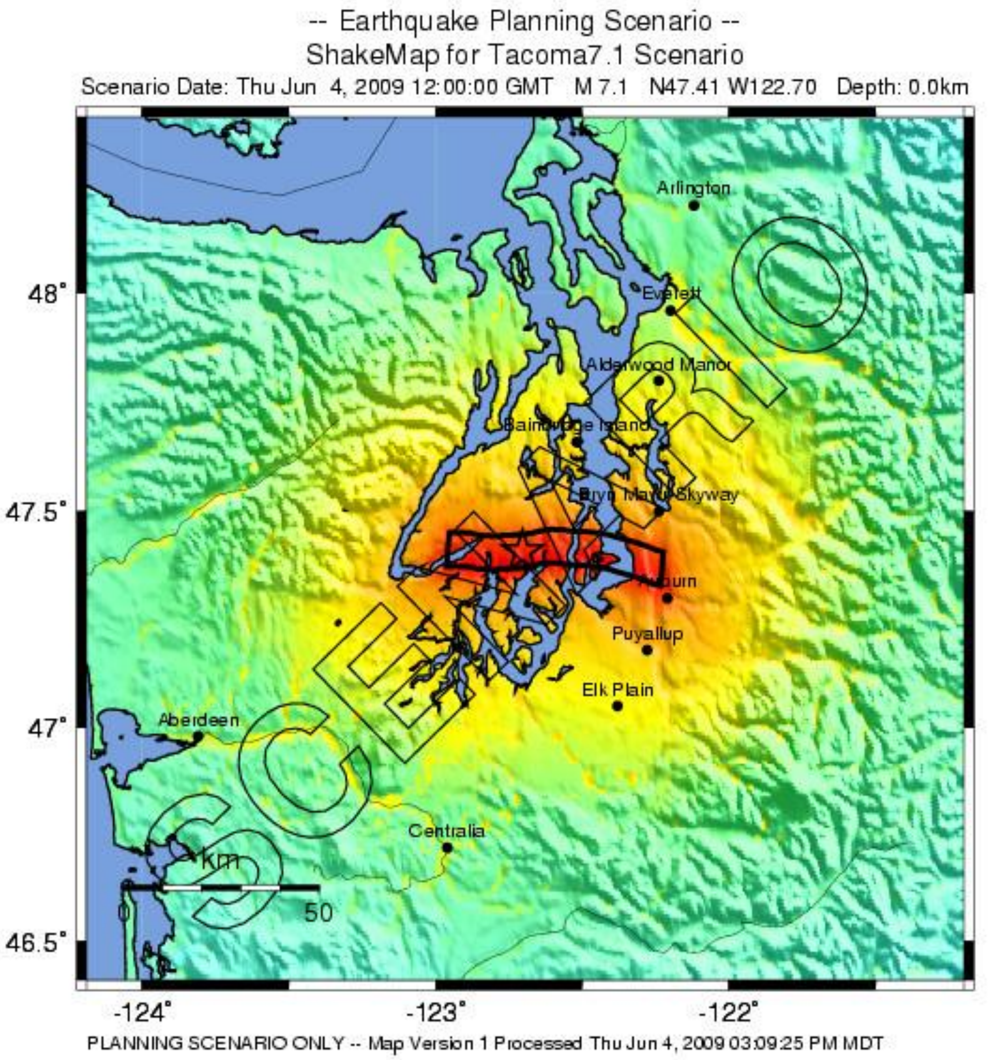
Generally, most of these ground motion models are considered well determined. Faults with estimates based on trenching (and in some cases uplift of coastal features) have at least some known history of movement. Likewise, the models for the two deep events are very well constrained, in part because of their familiar occurrence in Puget Sound. The parameters used to model Cascadia are well constrained, but certain characteristics of the ground motion (such as duration of strong shaking and the effect on long or tall structures) are not modeled. In some cases, such as Chelan, the historical record documents a strong earthquake, but the actual fault and fault parameters are still not known. The same is true for the Spokane models. Finally, the Mill Creek and Saddle Mountain scenarios are based on limited trenching but the fault traces themselves are known.

The Tacoma fault scenario (Figure 5.4-8) is an example of these new deterministic maps. For this map, seismologists picked specific traces of the mapped fault to break during an earthquake. With the fault trace and the magnitude of 7.1, seismologists then estimated the length of the fault, the depth of the

[1] Additional information on ShakeMaps and their usability can be found in the Earthquake Loss Avoidance Study (2013).

fault, its orientation in the earth, how much the fault moves to calculate the ground motions. The ground motions attenuate as they move away from the source and then are usually amplified by local geologic site conditions as the seismic waves reach the earth's surface.

Figure 38: Tacoma fault scenario. This is a deterministic model, as opposed to the probabilistic PGA seismic hazard maps in Figure 5.4-4 and 5.5-5. This map is for a single fault and does not represent the entire earthquake hazard in nearby communities.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Deep or Benioff Zone Earthquakes[64]

These earthquakes occur within the subducting Juan de Fuca plate at depths of 15 to 60 miles, although the largest events typically occur at depths of about 25 to 40 miles. They may produce events with magnitudes exceeding 9.0. Until recently the Olympia quake in 1949 was thought to be the largest of these deep earthquakes. The USGS recalculated this event, changing the magnitude from the original 7.1 to 6.8, the same size as the 2001 Nisqually event. Other significant Benioff zone events include the magnitude 6.5 Seattle-Tacoma quake in 1965, the magnitude 5.8 Satsop quake in 1999, and the magnitude 6.8 Nisqually quake of 2001. Strong shaking during the 1949 Olympia earthquake lasted about 20 seconds; during the 2001 Nisqually earthquake, strong shaking lasted about 15 to 20 seconds.

The probability of future occurrence for earthquakes similar to the 1965 magnitude 6.5 Seattle-Tacoma event and the 2001 magnitude 6.8 Nisqually event is about once every 35 years. The USGS has estimated that there is an 84% chance of a magnitude 6.5 or greater deep earthquake over the next 50 years.

Subduction Zone (Interplate) Earthquakes[65,66]

These earthquakes occur along the interface between tectonic plates. Scientists have found evidence of great-magnitude earthquakes along the Cascadia Subduction Zone. These earthquakes are very powerful, with a magnitude of 8 to 9 or greater; they have occurred at intervals ranging from as few as about 100 years to as long as 1,100 years. The last of these great earthquakes struck Washington in 1700. Scientists currently estimate that a magnitude 9 earthquake in the Cascadia Subduction Zone occurs about once every 500 years.

Subduction zone earthquakes are particularly dangerous in that they produce strong ground motions and in nearly all cases, damaging tsunamis. Along the Washington coast, the red colors in Figure 5.4-4 indicate that very strong shaking is anticipated there. A seismic wave loses energy as it propagates through the earth (attenuation). Along the Puget Sound Basin, the ground shaking will be attenuated by the greater distance from the source zone, but significant damage will result. Tall buildings and long bridges may be especially susceptible to long-period ground shaking produced on the subduction zone. Finally, the long-period motions of the seismic wave may affect the large dam structures in eastern Washington and can generate standing waves or seiches in susceptible water bodies like reservoirs.

Shallow or crustal Earthquakes[67]

These earthquakes occur in the earth's crust within the upper part of the North American plate (Figure 5.4-7). Crustal earthquakes are shallow earthquakes, typically within the upper 5 or 10 miles of the earth's surface and some ruptures may reach the surface. Although there are numerous examples of moderate magnitude shallow earthquakes occurring in Washington, most of these events cannot be directly related to an individual fault. Recent examples in western Washington are earthquakes near Bremerton in 1997, Duvall in 1996, off Maury Island in 1995, near Deming in 1990, near North Bend in 1945, just north of Portland in 1962, and at Elk Lake on the St. Helens seismic zone (a fault zone running north-northwest through Mount St. Helens) in 1981. These earthquakes had a magnitude of 5 to 5.5.

The 1872 earthquake near Lake Chelan was the state's most widely felt shallow earthquake. The magnitude for this event has been estimated at 7.4. The 1936 magnitude 6.1 earthquake near Walla Walla was also a shallow event. Because of their remote locations damage was light from these two quakes.

Of the three earthquake sources, the shallow zone is the least understood. Until 2000, geologists had not located a fault trace, where deformation breaks to the surface, anywhere in the Puget lowlands. Without knowing the location of fault traces, geologists were unable to determine how often faults moved and how large their movements were. Therefore, they were unable to determine how often these events occurred. This has changed dramatically with the development of Light Detection and Ranging (LiDAR), a technique that can generally penetrate forest canopy and vegetation to image the actual ground surface with an unprecedented accuracy of approximately one foot (30 cm). Since 2000, geologists have documented at least 12 major faults with recent motion in the Puget Sound region. A systematic assessment of earthquake hazards in eastern Washington started in 2008.

The findings of ongoing research on surface faults (see below) may lead to an assessment of greater earthquake risk in parts of Washington.

Puget Lowland [68, 69, 70, 71, 72]

Recent geologic studies have greatly enhanced scientists' ability to locate and study active faults, particularly in the Puget Sound basin. Using a combination of aeromagnetic surveys, high-resolution light detecting and ranging data (LiDAR), and geological field investigation, studies have documented about a dozen active faults or fault zones in the greater Puget Sound basin (Figure 5.4-9). Field evidence shows magnitude 7 or greater earthquakes occurred on at least eight of these faults. These faults include: the Seattle fault, Tacoma fault, Darrington-Devils Mountain fault, Utsalady Point fault, Southern Whidbey Island fault, Frigid Creek fault, Canyon River fault and the Lake Creek fault.

While investigation continues on Puget Lowland faults in an effort to better define the recurrence and magnitude, scientists already have learned much about them. For example, evidence points to a magnitude 7 or greater earthquake on the Seattle fault about 900 A.D. Such evidence includes a tsunami deposit in Puget Sound, landslides in Lake Washington, rockslides on nearby mountains, and a seven-meter uplift of a marine terrace.

An earthquake with such a magnitude today would cause tremendous damage and economic disruption throughout the central Puget Sound region. Using estimates of damage and loss developed in the scenario for a magnitude 6.7 event on the Seattle fault showed such a quake would result in extensive or complete damage to more than 58,000 buildings with a loss of $36 billion, more than 55,000 displaced households, and up to 2,400 deaths and 800 injuries requiring hospitalization. Although losses would likely be less from similar earthquakes on other Puget Sound faults away from the core of the Seattle urban area, all of the newly defined active faults represent the possibility of very high damage, loss of life, and major economic impact.

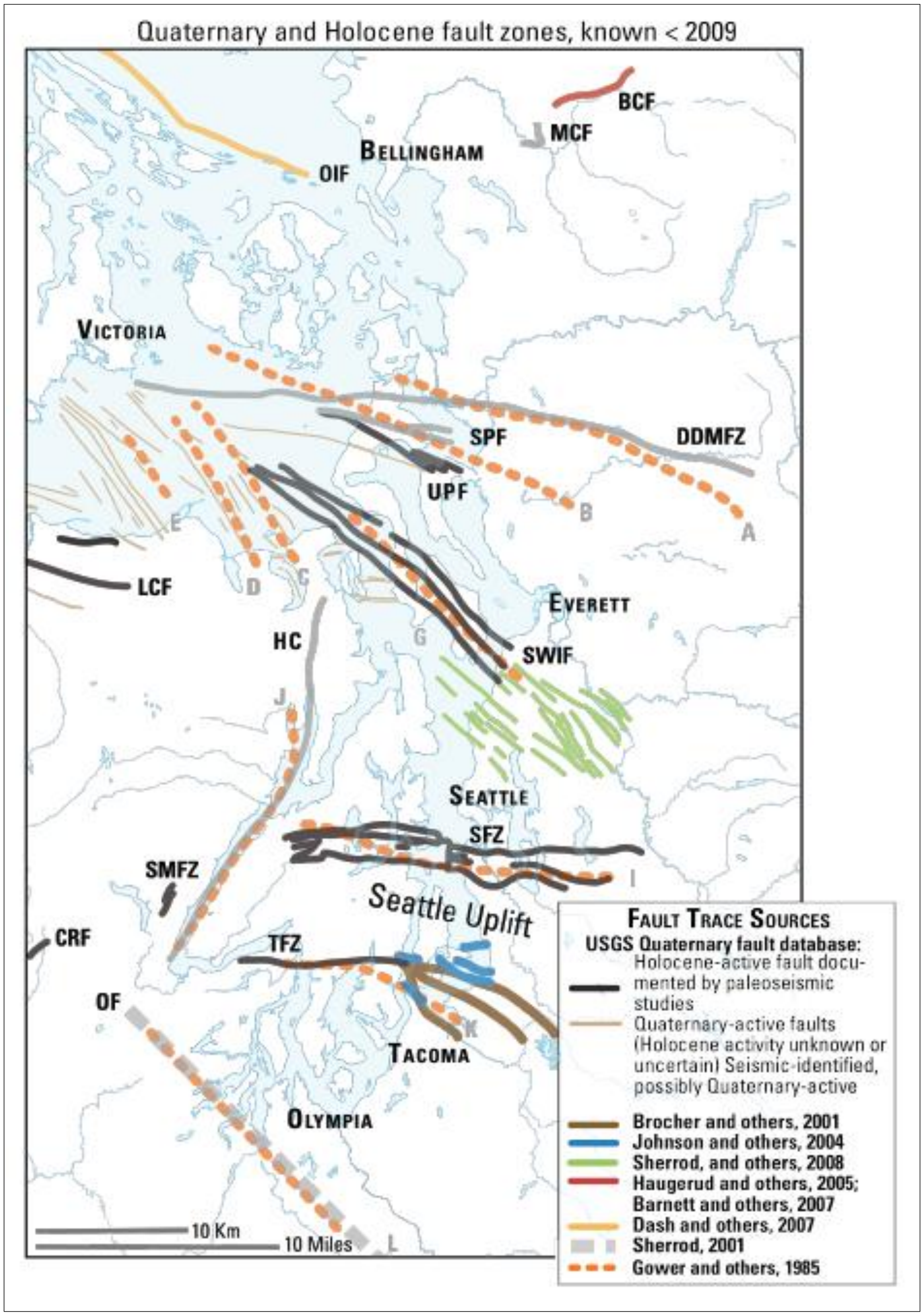
Scientists currently estimate the approximate recurrence rate of a magnitude 6.5 or greater earthquake on the Seattle Fault at about once every 1,000 years and for an earthquake of this magnitude anywhere on a fault in the Puget Sound basin to be once in about 350 years. Several known earthquake faults in the Puget Sound areas area shown below in Figure 5.4-9

Figure 39. Known earthquake crustal faults in the greater Puget Sound area.

The map shows the location of faults under study by earth scientists. Active faults as determined by documented evidence of Holocene surface deformation or surface rupture are abbreviated as:

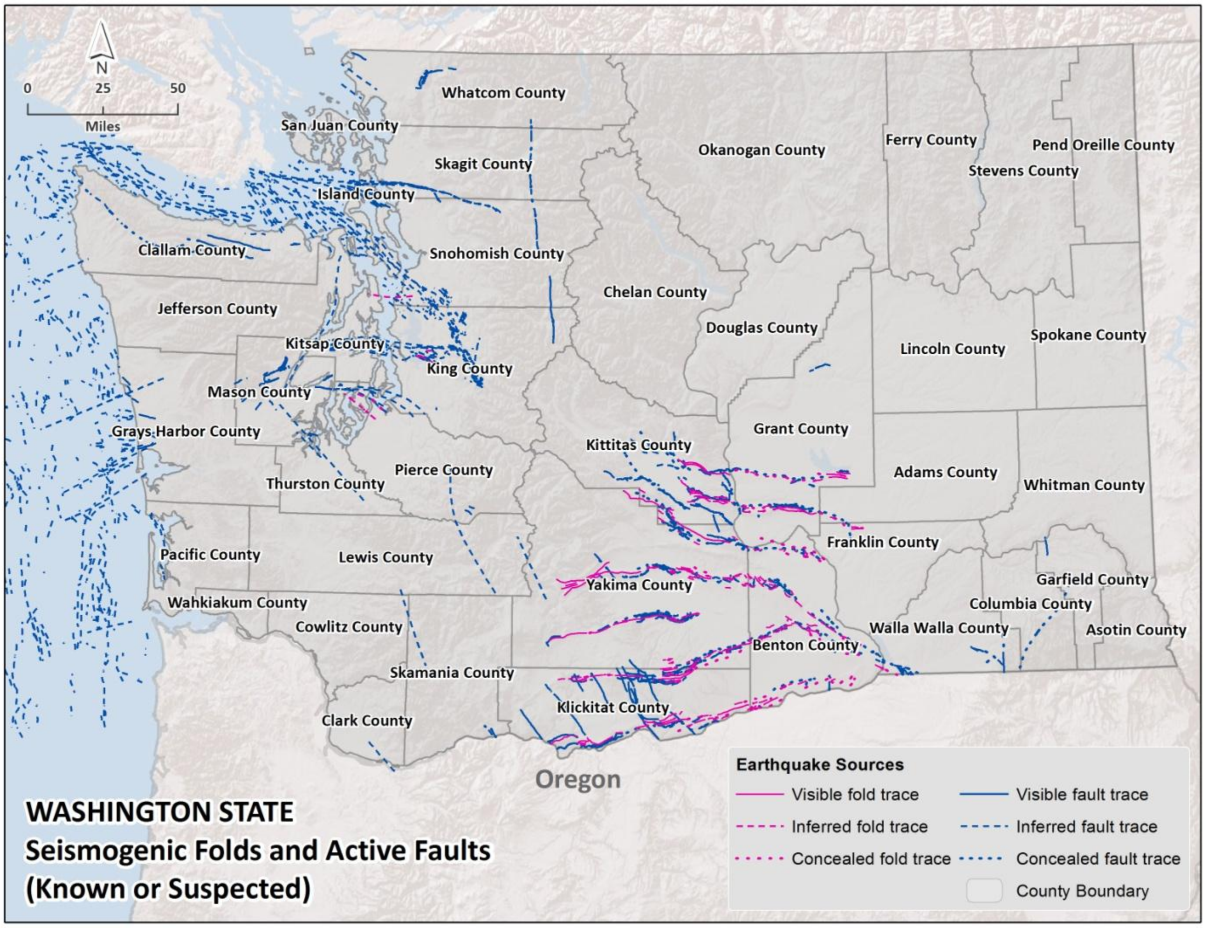
BCF, Boulder Creek fault;
OIF, Outer Island fault,
DDMFX, Devils Mountain-Darrington fault zone,
UPF, Utsalady Point fault;
LCF, Lake Creek fault,
SWIF, Southern Whidbey Island fault;
SFZ, Seattle fault zone;
TFZ, Tacoma fault zone;
SMFZ, Saddle Mountain fault zone;
CRF, Canyon River fault zone.

Source: USGS and Washington DNR.



Fault zones and seismogenic fold zones in Washington which are known to be active of suspected of being active by the Washington State Department of Natural Resources are shown in Figure 40.

Figure 40 Faults and Seismogenic Folds in Washington Known or Suspected to be Active[73]



Eastern Washington[74, 75, 76]

The state's two largest crustal earthquakes felt by European settlers occurred in Eastern Washington – the 1872 quake near Lake Chelan and the 1936 earthquake near Walla Walla. More recently, residents of Spokane strongly felt a swarm of earthquakes in 2001; the largest earthquake in the swarm had a magnitude of 4.0.

The recent Spokane earthquakes were very shallow, with most events located within a few miles of the surface. The events occurred near a suspected fault informally called the Latah Fault; however, the relation between the fault and the swarm is uncertain. Geologists have mapped the Spokane area, but none confirmed the presence of major faults that might be capable of producing earthquakes. State geologists continue to investigate the local geology and earthquake risk in Spokane.

Elsewhere in Eastern Washington, geologists have uncovered evidence of a number of surface faults; however, they have not yet determined how active the faults are, nor determined the extent of the risk they pose to the public. One fault, Toppenish Ridge, appears to have been the source of two earthquakes with magnitudes of 6.5 to 7.3 in the past 10,000 years.

Forecasting Future Earthquakes[77]

The size of a fault segment, the stiffness of rocks, and the amount of accumulated strain energy combine to control the magnitude and timing of earthquakes. Fault segments most likely to break can be identified where faults and plate motions are well known. If a fault segment is known to have broken in a past large earthquake, recurrence time and probable magnitude can be estimated based on fault segment size, rupture history, and accumulation of strain. Such a forecast, however, can be used only for well-understood faults, such as the San Andreas fault in California. No such forecasts can be made for poorly understood faults. Faults in the Pacific Northwest are complex, and research on them is continuing. It is not yet possible to forecast when any particular fault in Washington State will break.

Earthquake Effects

Earthquakes cause damage by strong ground shaking and by the secondary effects of ground failures, tsunamis, and seiches. The strength of ground shaking generally decreases with distance from the earthquake source. Shaking can be much higher when soft soils amplify earthquake waves. West Seattle and downtown Olympia are examples where amplification repeatedly has occurred and ground shaking was much stronger than in other nearby areas.

Ground failures caused by earthquakes include fault rupture, ground cracking, lateral spreading, slumps, landslides, rock falls, liquefaction, localized uplift and subsidence. Faults often do not rupture through to the surface. Unstable or unconsolidated soil is most at risk. Any of these failures will affect structures above or below them.

Large and disastrous landslides can often result from an earthquake. Soil liquefaction describes a phenomenon whereby a saturated soil substantially loses strength and stiffness in response to an applied stress like an earthquake's ground shaking, causing it to behave like a liquid. Liquefaction can cause building foundations to fail and low-density structures such as underground fuel tanks and pilings to float. Liquefactions examples can be seen in Figures 5.4-11 and Figure 5.4-12 below.

Figure 41. Japan's Niigata Earthquake, 1964. Source: Wikipedia.

Figure 42. New Zealand's Christchurch Earthquake, 2011. Source: Wikipedia.

Tsunamis are waves that result from the displacement of the water column by changes in the sea floor, by landslides or submarine slides, or by volcanic explosions in the water. Tsunamis can also be created by crustal earthquakes, such as the Seattle Fault System and the Tacoma Fault System which cross parts of Puget Sound because these earthquakes are likely to include vertical movements of the floor of the sound which will generate tsunamis. In fact, the Seattle Fault and Cascadia Subduction Zone earthquakes, however, have caused tsunamis. The warning times for such tsunamis would be only a few minutes. Washington is also at risk from tsunamis from distant earthquakes (see the Tsunamis Hazard Profile for more information on their impacts).

A similar earthquake phenomenon is "seiches" which are standing waves in an enclosed or partially enclosed body of water similar to sloshing waves in a bathtub. Historically, Washington has had minor damage from seiches. Seiches may result in damages to docks and other shoreline or near-shore structures. Seiches within water tanks may also results in roof damage or, in extreme case, rupture of the entire tank with resulting flooding.

As noted above , in terms of economic impact, Washington ranks second in the nation after California among states susceptible to economic loss caused by earthquake, according to a Federal Emergency Management Agency (FEMA) study. The study predicts that the state faces a probable annualized economic loss of $366 million due to earthquake; average annualized loss is an equivalent measure of future losses averaged on an annual basis. The Seattle-Tacoma-Bellevue area is fifth and Tacoma is 22nd on a list of metropolitan areas with more than $10 million in annualized earthquake losses.

Earthquake Monitoring Entities in Washington State

The USGS Earthquake Hazards Program is part of the National Earthquake Hazards Reduction Program (NEHRP), established by Congress in 1977. They monitor and report earthquakes, assess earthquake impacts and hazards, and research the causes and effects of earthquake.

The Cascade Volcano Observatory monitors the Washington State volcanoes for unrest and eruptive behavior and provides an early warning system.

The Pacific Northwest Seismic Network (PNSN) monitors ground motions within the region in order to better understand earthquake and volcano hazards and their impacts on the physical, economic, political, and social environment; provides the most accurate information about earthquakes and volcanoes as rapidly as possible to public officials, the public, and for education; and advocates comprehensive and cost-effective measures for reducing the harmful effects of earthquakes and volcanoes.

Previous Occurrences

Washington State, especially the Puget Sound basin, has a history of relatively frequent damaging earthquakes. Large earthquakes in 1946 (magnitude 5.8), 1949 (magnitude 7.1) and 1965 (magnitude 6.5) killed 15 people and caused more than $200 million (1984 dollars) in damage throughout several counties. The state has experienced at least 20 damaging events in the last 125 years. This averages to about one earthquake every 6 years though the interval time in between earthquakes is unpredictable.

The Nisqually earthquake on February 28, 2001 was the most recent damaging earthquake. This was a deep earthquake of magnitude 6.8 earthquake. It was centered about 10 miles northeast of Olympia and at a depth of about 30 miles. One person died of a stress induced heart attack, 407 people were injured of which 4 were considered serious, and estimates place damage at $2 billion. Table 5.4-4 shows selected damaging earthquakes in Washington.

Table 24. Selected Earthquakes of Washington State, Magnitude 5.0 or Greater*[78]

Date/Time (standard)	Depth	Moment Magnitude	Location
12/14/1872, 9:40 p.m.	0.0 km	6.8 (est.)	1.4 km SE of Chelan
01/11/1909, 3:49 p.m.	31.0 km	6.0	23.8 km NE of Friday Harbor
07/17/1932, 10:01 p.m.	0.0 km	5.7	15.6 km SE of Granite Falls
07/15/1936, 11:07 p.m.	0.0 km	6.1	8.1 km SSE of Walla Walla
11/12/1939, 11:45 p.m.	31.0 km	6.2	18.7 km S of Bremerton
04/29/1945, 12:16 p.m.	0.0 km	5.7	12.5 km SSE of North Bend
02/14/1946, 7:14 p.m.	25.0 km	5.8	28.4 km N of Olympia
04/13/1949, 11:55 a.m.	54.0 km	6.8	12.3 km ENE of Olympia
04/29/1965, 7:28 a.m.	57.0 km	6.7	18.3 km N of Tacoma
05/18/1980, 7:32 a.m.	2.8 km	5.7	1.0 km NNE of Mt St Helens
02/13/1981, 10:09 p.m.	7.3 km	5.5	1.8 km N of Elk Lake
01/28/1995, 7:11 p.m.	15.8 km	5.0	17.5 km NNE of Tacoma
07/02/1996, 8:04 p.m.	4.3 km	5.4	8.5 km ENE of Duvall
07/02/1999, 6:44 p.m.	40.7 km	5.8	8.0 km N of Satsop
02/28/2001, 10:54 a.m.	51.9 km	6.8	17.0 km NE of Olympia
06/10/2001, 5:19 a.m.	40.7 km	5.0	18.3 km N of Satsop

*Note: no earthquakes of magnitude 5.0 or greater have occurred since 2001.

The impacts caused by the earthquakes shaded in the table above are described in narratives below.

Lake Chelan – December 14, 1872[79]

The magnitude 6.8 (est.) earthquake occurred about 9:40 p.m. This earthquake was felt from British Columbia to Oregon and from the Pacific Ocean to Montana. The location for this earthquake was most likely northeast of the town of Chelan. Because there were few man-made structures in the epicenter area near Lake Chelan, most of the information available is about ground effects, including huge landslides, massive fissures in the ground, and a 27-foot high geyser.

Extensive landslides occurred in the slide-prone shorelines of the Columbia River. One massive slide, at Ribbon Cliff between Entiat and Winesap, blocked the Columbia River for several hours. A field reconnaissance to the Ribbon Cliff landslide area in August 1976 showed remnants of a large landslide mass along the west edge of Lake Entiat (Columbia River Reservoir), below Ribbon Cliffs and about 3 kilometers north of Entiat. Although the most spectacular landslides occurred in the Chelan-Wenatchee area, slides occurred throughout the Cascade Mountains.

Most of the ground fissures occurred in the following areas: at the east end of Lake Chelan in the area of the Indian camp; in the Chelan Landing-Chelan Falls area; on a mountain about 12 miles west of the Indian camp area; on the east side of the Columbia River (where three springs formed); and near the top of a ridge on a hogback on the east side of the Columbia River. These fissures formed in several locations. Slope failure, settlements, or slumping in water-saturated soils may have produced the fissures in areas on steep slopes or near bodies of water. Sulfurous water was emitted from the large fissures that formed in the Indian camp area. At Chelan Falls, "a great hole opened in the earth" from which water spouted as much as 27 feet in the air. The geyser activity continued for several days, and, after diminishing, left permanent springs.

Reports of structural damage are limited because of the epicenter's remote location. Heavy damage occurred to a log building near the mouth of the Wenatchee River. Ground shaking threw people to the floor, wave ripples were observed in the ground, and loud detonations heard. About two miles above the Ribbon Cliff slide area, the logs on another cabin caved in.

Damaging ground shaking extended to the west throughout the Puget Sound basin and to the southeast beyond the Hanford Site. Individuals in Idaho, Montana, Oregon, and Canada felt the earthquake. Aftershocks occurred in the area for two years.

State-Line Earthquake – July 15, 1936[80, 81, 82]

The earthquake, magnitude 6.1, occurred at 11:05 a.m. The epicenter was about 5 miles south-southeast of Walla Walla. It was widely felt through Oregon, Washington and northern Idaho, with the greatest shaking occurring in Northeast Oregon. Property damage was estimated at $100,000 (in 1936 dollars) in this sparsely populated area.

The earthquake moved small objects, rattled windows, and cracked plaster in the communities of Colfax, Hooper, Page, Pomeroy, Prescott, Touchet, Wallula, and Wheeler. However, most of the impact and damage was in the Walla Walla area. The earthquake alarmed residents of Walla Walla, many of whom fled their homes for the street. People reported hearing moderately loud rumbling immediately before the first shock. Standing pictures shook down, some movable objects changed positions, and doors partially opened. The earthquake was more noticeable on floors higher than the ground floor. It knocked down a few chimneys and many loose chimney brick; damaged a brick home used by the warden at the State Penitentiary that was condemned and declared unsafe; and damaged the local railroad station. Several homes moved an inch or less on their foundations, Five miles southwest of Walla Walla, the quake restored the flow of a weakened 600-foot deep artesian well to close to original strength; the flow had not diminished after several months. Walla Walla residents reported about 15 - 20 aftershocks.

Olympia Earthquake – April 13, 1949[83, 84]

The earthquake, magnitude 6.8, occurred at 11:55 a.m. The epicenter was about eight miles north-northeast of Olympia, along the southern edge of Puget Sound. Property damage in Olympia, Seattle, and Tacoma was estimated at $25 million (in 1949 dollars); eight people were killed, and many were injured.

School buildings in widely separated towns were seriously damaged. Thirty schools serving 10,000 students were damaged; 10 were condemned and permanently closed. Chimneys on more than 10,000 homes required repair. Water spouted from cracks that formed in the ground at Centralia, Longview, and Seattle. One new spring developed on a farm at Forest. Ground water, released by the shaking, flooded several blocks of Puyallup. Downed chimneys and walls were reported in towns throughout the area.

In Olympia, damage primarily was confined to the old part of the city and to areas of the port built on artificial fill. Most large buildings were damaged, including eight structures on the Capitol grounds. Many chimneys and two large smokestacks fell. Public utilities sustained serious damage; water and gas mains were broken and electric and telegraph services were interrupted. Breaks in 24 water mains temporarily closed the downtown business district.

In Centralia, the earthquake damaged 40 percent of the homes and businesses; two schools and a church were condemned; and the city's gravity-feed water system badly damaged. In Chehalis, damage occurred to four schools, city hall, the library, and county court house; the library was condemned. Seventy-five percent of the chimneys had to be replaced.

In Seattle, houses on filled ground were demolished, many old brick buildings were damaged, and chimneys toppled. One wooden water tank and the top of a radio tower collapsed. A 60-inch main broke at the city's water reservoir. Power failures occurred when swinging transmission lines touched, causing circuit breakers to trip. The gas distribution system broke at nearly 100 points, primarily due to damage caused by ground failure. Three damaged schools were demolished, and one rebuilt.

In Tacoma, many chimneys of older structures were knocked to the ground and many buildings were damaged. Water mains broke from landslides and settling in the t ide flats. Transformers at the Bonneville Power Administration substation were thrown out of alignment. Near Tacoma, a huge section of a 200-foot cliff toppled into Puget Sound three days after the earthquake that produced a tsunami that swept across Tacoma Narrows and reflected back to Tacoma, flooding a group of houses along the shoreline. South of Tacoma, railroad bridges were thrown out of alignment. A 23-ton cable saddle was thrown from the top of a Tacoma Narrows bridge tower, causing considerable damage.

The earthquake was felt in Idaho, Montana, Oregon, and in British Columbia, Canada. Only one small aftershock occurred during the next six months.

***Seattle-Tacoma Earthquake – April 29, 1965*[85, 86]**

The earthquake, magnitude 6.7, struck the Puget Sound area at 7:28 a.m. The epicenter was about 12 miles north of Tacoma at a depth of about 40 miles. The earthquake caused about $12.5 million (in 1965 dollars) in property damage and killed seven people.

A rather large area of ground shaking in Seattle and its suburbs, including Issaquah, characterized the quake. Pockets of intense ground shaking, seen in damage such as fallen chimneys, were associated with variations in the local geology. In general, damage patterns repeated those observed in the April 1949 earthquake, although that event was more destructive. Buildings damaged in 1949 often sustained additional damage in 1965.

Most damage in Seattle was concentrated in areas of filled ground, including Pioneer Square and the waterfront, both with many older masonry buildings; nearly every waterfront building experienced damage. Eight schools serving 8,800 students were closed temporarily until safety inspections could be completed; two schools were severely damaged. Extensive chimney damage occurred in West Seattle. The low-lying and filled areas along the Duwamish River and its mouth settled, causing severe damage at Harbor Island; slumping occurred along a steep slope near Admiral Way. A brick garage partly collapsed at Issaquah; one school was damaged extensively; and chimneys in the area sustained heavy damage. Many instances of parapet and gable failure occurred. Damage to utilities in the area was not severe as in 1949.

Also damaged were two electric transmission towers in a Bonneville Power Administration substation near Everett; the towers each supported 230,000-volt lines carrying power from Chief Joseph Dam to the substation. Three water mains failed in Seattle, and two of three 48-inch water supply lines broke in Everett.

Buildings with unreinforced brick-bearing walls with sand-lime mortar were damaged most severely. Multistory buildings generally had slight or no damage. However, the Legislative Building once again was damaged and temporarily closed; government activities moved to nearby motels. Performance of wood frame dwellings was excellent, with damage confined mainly to cracks in plaster or to failure of unreinforced brick chimneys near the roofline.

The earthquake was felt in Idaho, Montana, Oregon, and in British Columbia, Canada; little aftershock activity was observed.

***Nisqually Earthquake – February 28, 2001*[87, 88]**

The earthquake, magnitude 6.8, struck the Puget Sound area at 10:54 a.m. The epicenter was below Anderson Island near the Nisqually River delta in Puget Sound about 50 miles south of Seattle and 11 miles northeast of Olympia. Ground shaking lasted about 20 seconds. Two minor aftershocks occurred near the epicenter of the main shock. This event was a slab earthquake; its depth calculated at 32 miles below the earth's surface in the Juan de Fuca plate.

The area of most intense ground shaking occurred along the heavily populated north-south Interstate 5 corridor, not around the epicenter. This was due to the amplification of the earthquake waves on softer river valley sediments. The earthquake was felt over a large area – from Vancouver, British Columbia, to the north; to Portland, Oregon, to the south; and Salt Lake City, Utah, to the southeast.

The six counties most severely damaged by the earthquake – King, Kitsap, Lewis, Mason, Pierce, and Thurston – were declared federal disaster areas one day after the event. Eventually, 24 counties received disaster declarations for Stafford Act assistance under Federal Disaster #1361. Stafford Act disaster assistance provided was $155.9 million. Small Business Administration disaster loans approved - $84.3 million. Federal Highway Administration emergency relief provided to date - $93.8 million.

Various estimates have placed damage to public, business and household property caused by the Nisqually earthquake at from $1 billion to $4 billion. A 2002 study by the University of Washington funded by the National Science Foundation estimated the quake caused $1.5 billion in damages to nearly 300,000 households. A second study, also by the University of Washington and funded by the Economic Development Administration of the U.S. Department of Commerce, estimated that 20 percent of small businesses in the region affected by the quake had a direct physical loss and 60 percent experienced productivity disruptions.

Severe damage occurred in Olympia, at SeaTac Airport, and in south Seattle in the Pioneer Square and Sodo areas. Structures damaged included office buildings, residences, schools, hospitals, airport facilities and churches. Many damaged structures and surrounding areas were closed for various lengths of time following the earthquake.

Structural damage was primarily concentrated in older, unreinforced masonry buildings built before 1950, with some damage reported to wood-frame structures and reinforced concrete structures. In general, new buildings and buildings that had recently been seismically upgraded typically displayed good structural performance, but many still sustained non-structural damage.

In the major urban areas of King, Pierce and Thurston counties, 1,000 buildings were rapidly assessed immediately following the earthquake. Of these, 48 buildings were red-tagged, indicating serious damage, and 234 were yellow-tagged indicating moderate damage.

Damaged significantly were several state government buildings in Olympia, including the Legislative Building (the state's Capitol Building). The dome of the 74-year-old building sustained a deep crack in its limestone exterior and damage to supporting columns. There was non-structural damage which occurred throughout the building. Most other state agency buildings closed for one or more days for inspection and repair.

Lifeline systems generally performed well during the event. Water utilities reported minor structural damages; a number of wells in Eastern Washington reportedly went dry. A gas-line leak caused a fire and explosion when two maintenance workers were resetting an earthquake valve at a correctional facility near Olympia. Seattle City Light reported 17,000 customer power outages, and Puget Sound Energy reported 200,000 customers without power, but power was restored to most customers within a day. The volume of calls placed immediately after the earthquake overloaded landline and wireless communication systems.

Transportation systems also suffered damage. Seattle-Tacoma International Airport closed immediately because its control tower was disabled. A temporary backup control tower allowed reopening of the airport to limited traffic several hours after the quake. King County Airport (Boeing Field) suffered serious cracking and gaps on the runway due to soil liquefaction and lateral spreading. The main runway reopened for business a week later.

While the area's overall road network remained functional, many highways, roads, and bridges were damaged. Several state routes and local roadways closed due to slumping and pavement fractures. The quake badly damaged the Alaskan Way Viaduct (State Route 99), a major arterial in Seattle. Temporary repairs made the structure usable; various proposals to permanently repair or replace it run in the billions of dollars. Two local bridges closed due to significant damage – the Magnolia Bridge in Seattle and the Fourth Avenue Bridge in Olympia.

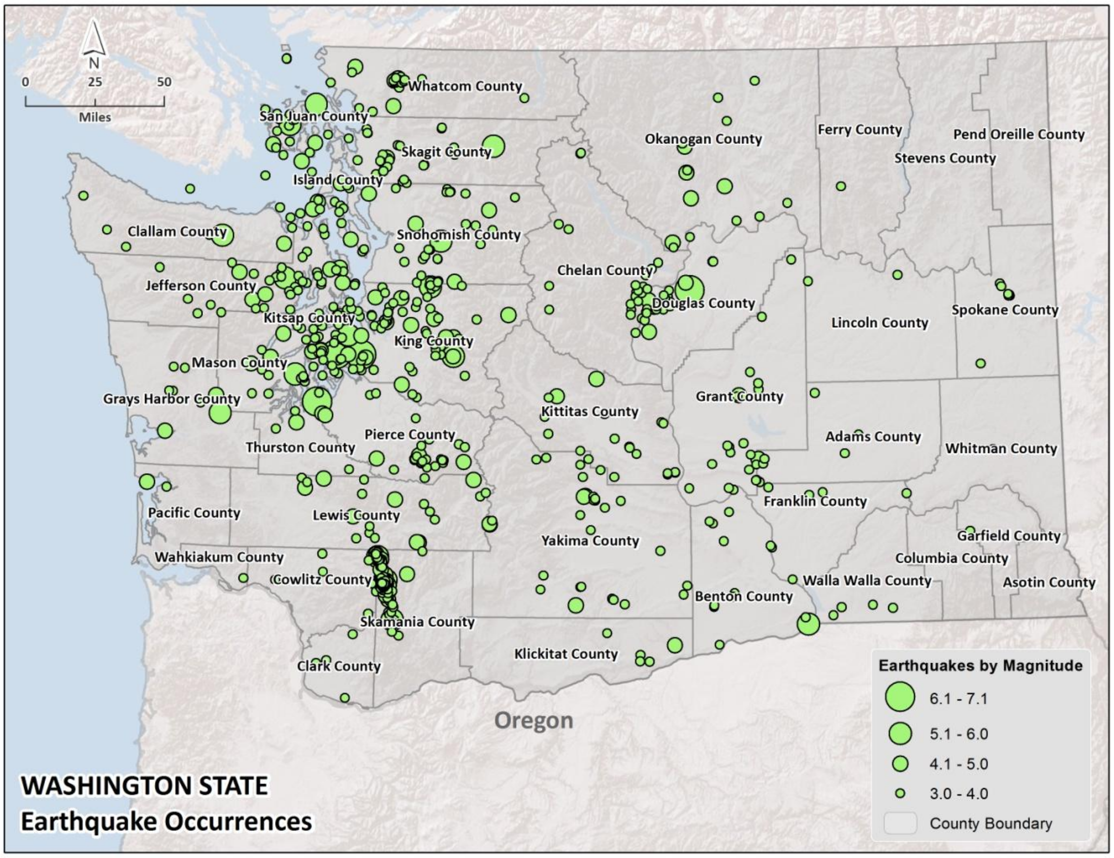
There was minor damage to dock facilities in both Tacoma and Seattle, but not extensive enough to interrupt commercial port services.

The state's dams fared well during the earthquake. Of the 290 dams inspected by state engineers, only five had earthquake-related damage; these dams were susceptible to damage due to their poor construction and weak foundations. Dams controlled or regulated by the Federal Energy Regulatory Commission, the Bureau of Reclamation, or the U.S. Army Corps of Engineers, were not damaged.

Damage to residential structures came in a variety of forms, from severe mudslide destruction of entire homes to breakage of replaceable personal property. A 2002 University of Washington study on residential loss estimated nearly 300,000 residential units – about one of every four Puget Sound households – experienced $1.5 billion in damage. The study indicates that structural damage to roofs, walls and foundations accounted for nearly two-thirds of losses, followed by chimney damage, and damages to nonstructural elements and household contents.[89]

It should also be noted that earthquakes of a lesser magnitude occur frequently in the state. Figure 5.4-13 below shown historic earthquakes in Washington State.

Figure 43 Historic Earthquake Epicenters with Magnitudes of 3.0 or Greater (1872 -2011)[90]

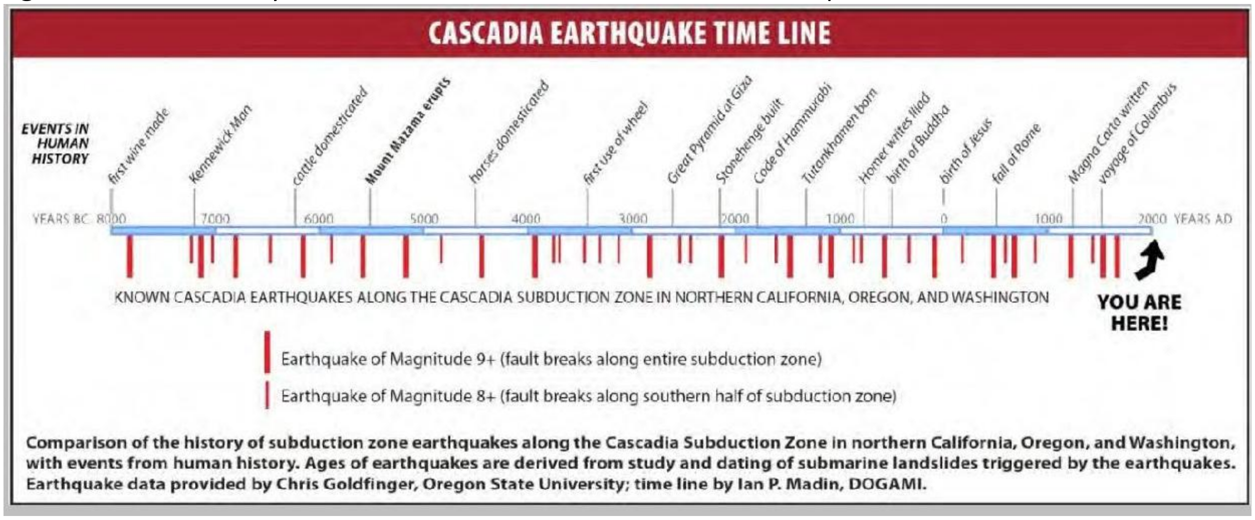


Probability of Future Events

As noted above, it is impossible to forecast earthquakes given our existing technology, but scientists can estimate general probability based on historic occurrences and location among other factors. The size of a fault segment, the stiffness of rocks, and the amount of accumulated strain energy combine to control the magnitude and timing of earthquakes. Fault segments most likely to break can be identified where faults and plate motions are well known. If a fault segment is known to have broken in a past large earthquake, recurrence time and probable magnitude can be estimated based on fault segment size, rupture history, and accumulation of strain.

Scientists currently estimate that a magnitude 9 earthquake in the Cascadia Subduction Zone occurs about once every 500 years. The last one was in 1700. Paleoseismic investigations have identified 41 Cascadia Subduction Zone interface earthquakes over the past 10,000 years, which corresponds to one earthquake about every 250 years. Of these 41 earthquakes, about half are M9.0 or greater earthquakes that represent full rupture of the fault zone from Northern California to British Columbia. The other half of the earthquakes represents M8+ earthquakes that rupture only the southern portion of the subduction zone.
The 300+ years since the last major Cascadia Subduction Zone earthquake is longer than the average of about 250 years for M8 or greater and shorter than some of the intervals between M9.0 earthquakes. The time history of these major earthquakes is shown below in Figure 5.4-14.

Figure 44. Time History of Cascadia Subduction Zone Interface Earthquakes[91]



Scientists currently estimate the probability of future occurrence for deep earthquakes similar to the 1965 magnitude 6.5 Seattle-Tacoma event and the 2001 magnitude 6.8 Nisqually event is about once every 35 years. The USGS has estimated that there is an 84% chance of a magnitude 6.5 or greater deep earthquake over the next 50 years.

Scientists currently estimate the approximate recurrence rate of a magnitude 6.5 or greater earthquake anywhere on a shallow fault in the Puget Sound basin to be once in about 350 years. There have been four earthquakes of less than magnitude 5 in the past twenty years.

Hazus-MH 2.1 Earthquake Methodology and Results

Hazus-MH is a geographic information system (GIS) - based earthquake loss estimation tool developed by the Federal Emergency Management Agency (FEMA) in cooperation with the National Institute of Building Sciences (NIBS). Hazus-MH 2.1 was used to calculate the Average Annualized Loss (AAL) and the Average Annualized Loss Ratios (AALR) for the State of Washington. In order to increase the reliability of the results, enhanced hazard data and inventory was utilized. Two user-supplied data layers for liquefaction and soil class were added to Hazus-MH to more accurately model the effects of the earthquake at each site-specific state facility. These data maps were supplied by the Washington Department of Natural Resources in their June 2010 Ground Response file geodatabase containing GIS data. The two datasets used in this scenario were: liquefaction susceptibility, which contain GIS polygons that provide information regarding the relative liquefaction potential for Washington State; and seismic site class, which contains polygons that provide NEHRP (National Earthquake Hazards Reduction Program) soil data information for Washington State. In addition, enhanced inventory data was provided for five counties courtesy of the Washington Hazus Users Group.[2]

The Average Annualized Loss addresses two key components of seismic risk: the probability of ground motion in terms of physical damage and economic loss. Average Annualized Loss also takes into account the regional variations in seismic risk. Average Annualized Loss annualizes expected losses by averaging losses per return period (100; 250; 500; 750; 1,000; 1,500; 2,000; and 2,500 years), which factors in historic patterns of smaller but more frequent earthquakes with those that are larger in magnitude but

[2] Additional information on the data updates can be found in Appendix A.

are infrequent in nature. This methodology enables the comparison of risk to occur between two geographic areas, such as Skagit County and Asotin County.

The Average Annualized Loss Ratio is the Average Annualized Loss presented as a fraction of the replacement value of the building inventory and is used for comparing the relative risk of a seismic event. Therefore, the annualized loss ratio allows for the relationship between the AAL and the building replacement values to be evaluated. This ratio can be used as a measure of relative risk between regions and within a state, since it is normalized by replacement value, allowing for the direct comparison across metropolitan areas, counties, and even between states.

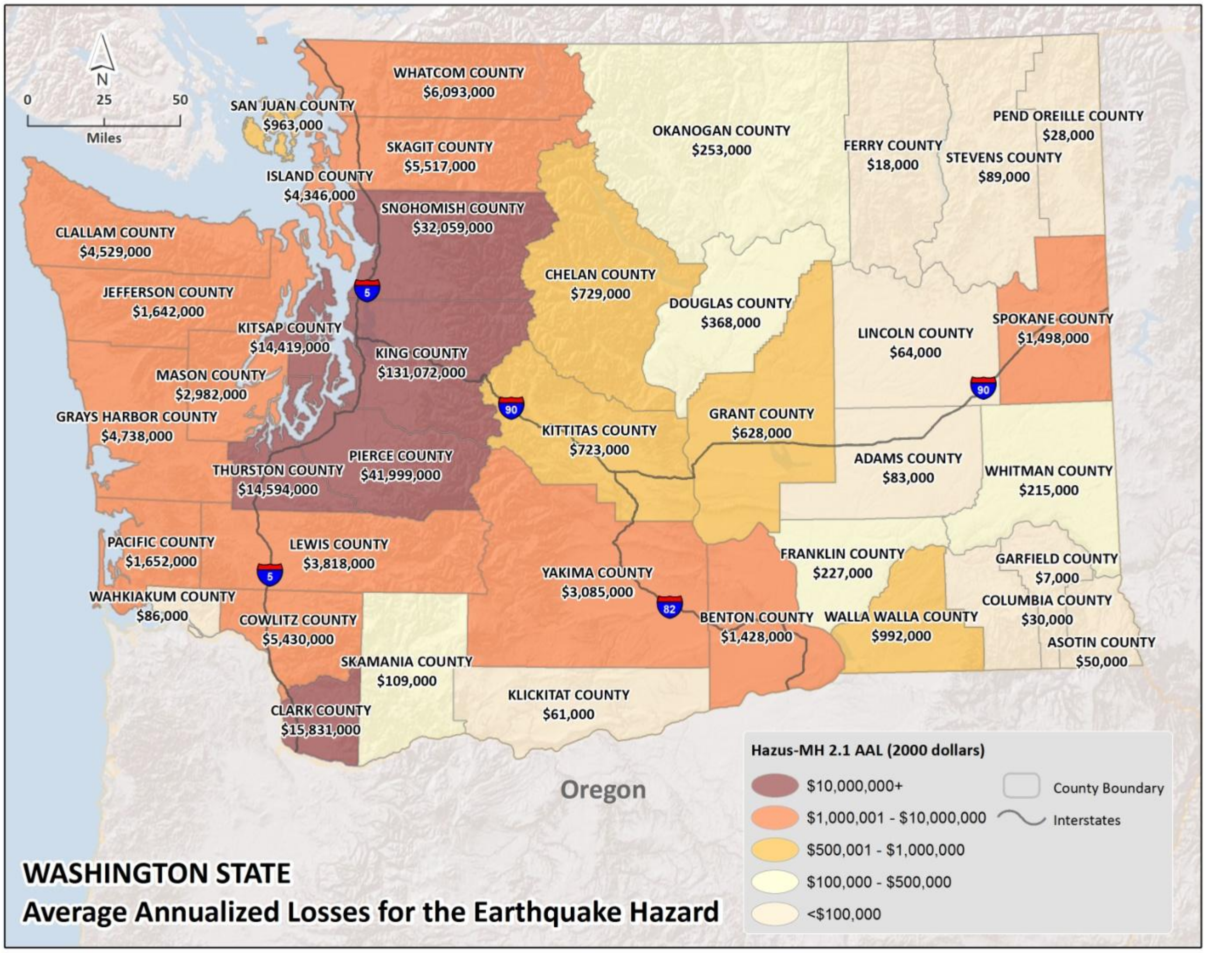
In addition to the Hazus-MH Average Annualized Loss analysis, inflation was accounted for in order to estimate approximate 2012 value of losses. The Consumer Price Index (CPI) is a common measure of inflation and was used herein. State CPI's are not determined but national and metropolitan-level (with populations over 1.5 million) values are calculated. According to the Washington Office of Financial Management, the Seattle Metropolitan Statistical Area CPI (including Seattle, Tacoma, and Bremerton) is the closest representative to a state CPI. It should also be noted that the CPI at the metropolitan level is subject to measurement errors and can be more volatile given the smaller area. According to the Seattle CPI, the cumulative rate of inflation between 2000 and 2012 was calculated to be 29.9 percent. In other words, $1.00 in 2000 is equivalent to $1.29 in 2012.[92] For comparison purposes, the national rate of inflation during this time was 33.3 percent.

The results of the AAL are shown in Table 5.4-5 and Figure 5.4-15 below.

Table 25. Earthquake Average Annualized Loss Estimates from Hazus-MH 2.1

County	Loss Ratio	Total Average Annualized Losses	Inflated to 2012 dollars
Adams County	0.01	$83,000	$107,070
Asotin County	0	$50,000	$64,500
Benton County	0.01	$1,428,000	$1,842,120
Chelan County	0.01	$729,000	$940,410
Clallam County	0.06	$4,529,000	$5,842,410
Clark County	0.04	$15,831,000	$20,421,990
Columbia County	0.01	$30,000	$38,700
Cowlitz County	0.05	$5,430,000	$7,004,700
Douglas County	0.01	$368,000	$474,720
Ferry County	0	$18,000	$23,220
Franklin County	0	$227,000	$292,830
Garfield County	0	$7,000	$9,030
Grant County	0.01	$628,000	$810,120
Grays Harbor County	0.06	$4,738,000	$6,112,020
Island County	0.05	$4,346,000	$5,606,340
Jefferson County	0.04	$1,642,000	$2,118,180
King County	0.05	$131,072,000	$169,082,880
Kitsap County	0.05	$14,419,000	$18,600,510
Kittitas County	0.02	$723,000	$932,670
Klickitat County	0	$61,000	$78,690
Lewis County	0.05	$3,818,000	$4,925,220
Lincoln County	0	$64,000	$82,560
Mason County	0.05	$2,982,000	$3,846,780
Okanogan County	0.01	$253,000	$326,370
Pacific County	0.05	$1,652,000	$2,131,080
Pend Oreille County	0	$28,000	$36,120
Pierce County	0.05	$41,999,000	$54,178,710
San Juan County	0.03	$963,000	$1,242,270
Skagit County	0.04	$5,517,000	$7,116,930
Skamania County	0.01	$109,000	$140,610
Snohomish County	0.04	$32,059,000	$41,356,110
Spokane County	0	$1,498,000	$1,932,420
Stevens County	0	$89,000	$114,810
Thurston County	0.06	$14,594,000	$18,826,260
Wahkiakum County	0.02	$86,000	$110,940
Walla Walla County	0.02	$992,000	$1,279,680
Whatcom County	0.03	$6,093,000	$7,859,970
Whitman County	0	$215,000	$277,350
Yakima County	0.01	$3,085,000	$3,979,650
Washington State	0.02	$302,456,000	$390,166,951

Figure 45. Average Annualized Losses from Hazus-MH 2.1



Casualties and injuries are also estimated in Hazus. Estimates are reported at three different times throughout the day including 2:00 AM (people are asleep in houses), 2:00 PM (people are working), and 5:00 PM (people are commuting from work). Injuries range from minor to requiring hospitalization. As would be expected, residential casualties are highest during the 2:00 AM estimate. The following table shows the annualized injury and fatalities based on these assumptions.

Table 26: Hazus Estimated Injuries and Fatalities

	2:00 AM		2:00 PM		5:00 PM	
Building Type	Injuries	Deaths	Injuries	Deaths	Injuries	Deaths
Commercial	1	0	106	7	77	5
Commuting	0	0	0	0	0	0
Educational	0	0	21	1	3	0
Hotels	1	0	0	0	0	0
Industrial	2	0	14	1	9	1
Other-Residential	42	1	9	0	16	1
Single Family	32	0	6	0	13	0
Total	78	1	156	8	118	7

Jurisdictions Most Threatened and Vulnerable to Earthquake Hazards

The primary factors used to determine the 26 counties that are most vulnerable to future earthquakes were the Annualized Earthquake Loss, as calculated by Hazus-MH 2.1 and the Annualized Earthquake Loss Ratio, as calculated by Hazus-MH 2.1. Counties considered most at risk are those with an Annualized Earthquake Loss of at least $1 million or with an Annualized Earthquake Loss Ratio equal or greater than the state's ratio of 0.02. Twenty-three counties meet one of these two criteria.

Additionally, Douglas and Franklin, which have greater seismic risk than most counties in Eastern Washington but do not have building stock to meet the above criteria, have been added to the list of jurisdictions most vulnerable at the advice of state and federal geologists and seismologists with expertise in earthquakes in Washington. This brings the total counties considered most vulnerable to earthquakes to twenty-five.

Other factors included the size of potentially vulnerable populations like people who do not speak English as their primary language, individuals with disabilities, senior citizens, people living in poverty, and children in school (kindergarten through 12th grade) plus the age of the housing stock built before 1960, when building codes were first enacted in Washington State.

Average Annualized Earthquake Loss and Annualized Earthquake Loss Ratio[93, 94]
A complete description of the Hazus-MH 2.1 Average Annualized Loss methodology can be found in the previous subsection ("Hazus-MH 2.1 Earthquake Methodology and Results"). As noted above, Average Annualized Loss factors in historic patterns of smaller but more frequent earthquakes with those that are larger in magnitude but are infrequent in nature. This methodology enables the comparison of risk to occur between different geographic areas and inputs.

The Average Annualized Loss Ratio is the Average Annualized Loss presented as a fraction of the replacement value of the building inventory and is used for comparing the relative risk of a seismic event. Therefore, the annualized loss ratio allows for the relationship between the AAL and the building replacement values to be evaluated. This ratio can be used as a measure of relative risk between regions and within a state, since it is normalized by replacement value, allowing for the direct comparison across metropolitan areas, counties, and even between states.

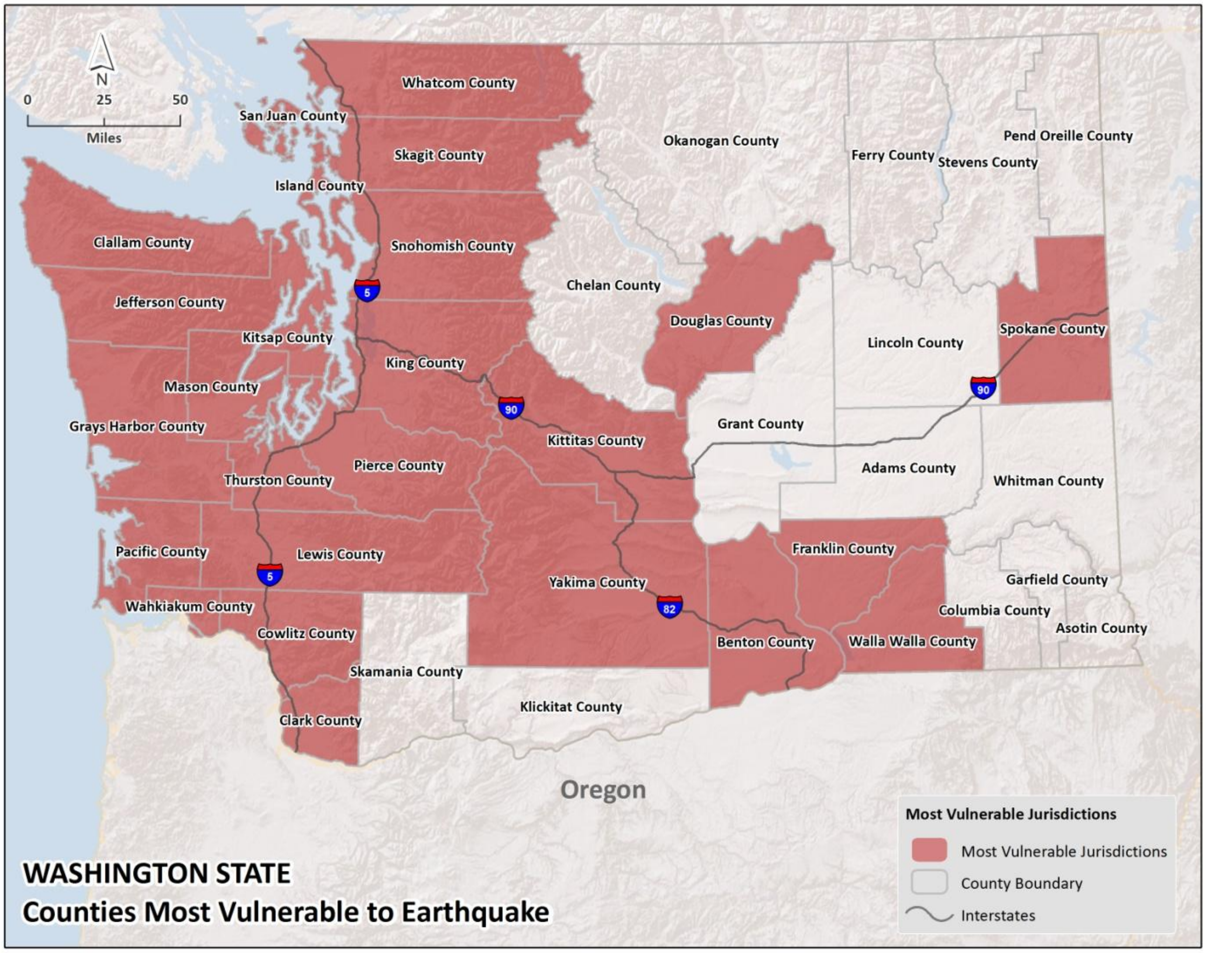
The Average Annualized Loss and Ratios calculated using Hazus-MH for each county in Washington State are not to be seen as determinations of total risk since not all aspects of earthquake are addressed. The value presented in Table 5.4-7 only represent the direct economic loss to buildings, and do not factor in such things as damage to lifelines and critical facilities and the indirect economic losses that can be sustained by communities and as a result of a seismic event. The Hazus-MH estimates annualized loss and annualized loss ratios were calculated using default inventory data for each county. As noted above, counties considered most at risk are those with an Annualized Earthquake Loss of at least $1 million or with an Annualized Earthquake Loss Ratio equal or greater than the state's ratio of 0.02. Twenty-five counties meet one of these two criteria.

Table 27. Average Annualized Loss Estimates from Hazus-MH 2.1

County	Loss Ratio	Total Average Annualized Losses
Clallam	0.06	$4,529,000
Grays Harbor	0.06	$4,738,000
Thurston	0.06	$14,594,000
Cowlitz	0.05	$5,430,000
Island	0.05	$4,346,000
King	0.05	$131,072,000
Kitsap	0.05	$14,419,000
Lewis	0.05	$3,818,000
Mason	0.05	$2,982,000
Pacific	0.05	$1,652,000
Pierce	0.05	$41,999,000
Clark	0.04	$15,831,000
Jefferson	0.04	$1,642,000
Skagit	0.04	$5,517,000
Snohomish	0.04	$32,059,000
San Juan	0.03	$963,000
Whatcom	0.03	$6,093,000
Kittitas	0.02	$723,000
Wahkiakum	0.02	$86,000
Walla Walla	0.02	$992,000
Adams	0.01	$83,000
Benton	0.01	$1,428,000
Chelan	0.01	$729,000
Columbia	0.01	$30,000
Douglas	0.01	$368,000
Grant	0.01	$628,000
Okanogan	0.01	$253,000
Skamania	0.01	$109,000
Yakima	0.01	$3,085,000
Asotin	0	$50,000
Ferry	0	$18,000
Franklin	0	$227,000
Garfield	0	$7,000
Klickitat	0	$61,000
Lincoln	0	$64,000
Pend Oreille	0	$28,000
Spokane	0	$1,498,000
Stevens	0	$89,000
Whitman	0	$215,000
Washington State	0.02	$302,456,000

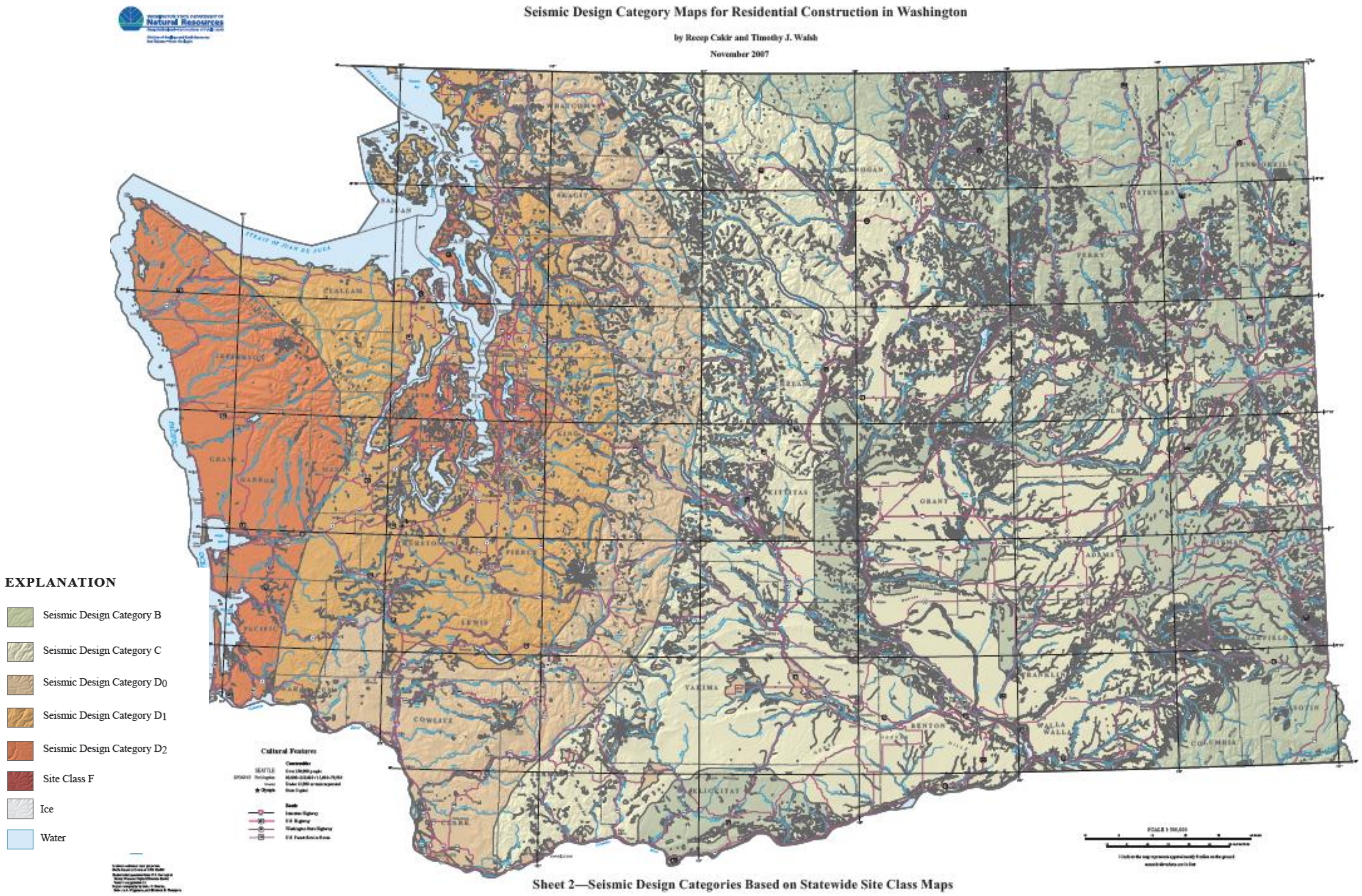
The following figure shows the location of the twenty-five most vulnerable jurisdictions to earthquake.

Figure 46. Jurisdictions Most Vulnerable to Earthquake



Building codes enforced at the time the structure was built does influence the buildings survivability to seismic events.

Figure 47. Seismic Design Category Map for Residential Construction in Washington State, 2007.



Source: http://pubs.usgs.gov/of/2009/1298/pdf/usgs_of2009-1298_cakir.pdf

Potential Impacts of Earthquakes

Much of the damage in earthquakes occurs from ground shaking that affects buildings and infrastructure. However, there are several other consequences of earthquakes that can result in substantially increased levels of damage in some locations. These consequences include: surface rupture, subsidence or elevation, liquefaction, settlement, lateral spreading, landslides, dam, reservoir or levee failures, tsunamis and seiches. Any of these consequences can result in very severe damage to buildings, up to and including complete destruction, and also a high likelihood of casualties.

Surface Rupture

Surface rupture occurs when the fault plane along which rupture occurs in an earthquake reaches the surface. Surface rupture may be horizontal and/or vertical displacement between the sides of the rupture plane. For a building subject to surface rupture the level of damage is typically very high and generally results in destruction of the building. Horizontal or vertical rupture through a building in a major earthquake means that two parts of the building are displaced by several feet in horizontal or vertical direction or both.

Surface rupture does not occur with interface or intraplate earthquakes on the Cascadia Subduction Zone and does not occur with all crustal earthquakes. Fault rupture for the Cascadia earthquakes and for many crustal earthquakes doesn't reach the earth's surface. However, surface rupture does when crustal earthquake fault ruptures reach and break the ground surface. Faults in Washington where surface rupture is likely include the Seattle Fault System and the Tacoma Fault System.

Subsidence or Uplift

Large interface earthquakes on the Cascadia Subduction Zone are expected to result in subsidence of up to several feet in many coastal locations, while other locations may be uplifted by several feet. For facilities located very near sea level, co-seismic subsidence may result in the facilities being below sea level or low enough so that flooding becomes very frequent. Subsidence may also impede egress by blocking some routes and thus increase the likelihood of casualties from tsunamis.

Subsidence or uplift may be fairly uniform over an area or be uneven due to variations in soil/rock type. Uneven subsidence or uplift may substantially increase building damages in a manner analogous to surface rupture.

Liquefaction, Settlement and Lateral Spreading

Liquefaction is a process where loose, wet sediments lose bearing strength during an earthquake and behave similar to a liquid. Once a soil liquefies, it tends to settle vertically and/or spread laterally. With even very slight slopes, liquefied soils tend to move sideways downhill (lateral spreading). Settling or lateral spreading can cause major damage to buildings and to buried infrastructure such as pipes and cables.

The Washington Department of Natural Resources (DNR) has made statewide estimates of liquefaction potential, based on available geological data. Liquefaction potential varies markedly with location, often over very short distances. Thus, it is not possible to show liquefaction potential maps except at high spatial resolution for small areas.

Landslides

Earthquakes can also induce landslides, especially if an earthquake occurs during the rainy season and soils are saturated with water. The areas prone to earthquake-induced landslides are largely the same as those areas prone to landslides in general. As with all landslides, areas of steep slopes with loose rock or soils and high water tables are most prone to earthquake-induced landslides (see the Landslide Profile for more information on their impacts).

Dam, Levee and Reservoir Failures

Earthquakes can also cause dam failures in several ways. The most common mode of earthquake-induced dam failure is slumping or settlement of earthfill dams where the fill has not been properly compacted. If the slumping occurs when the dam is full, then overtopping of the dam, with rapid erosion leading to dam failure is possible. Dam failure is also possible if strong ground motions heavily damage concrete dams. Earthquake induced landslides into reservoirs have also caused dam failures.

Earthquake-induced failures of levees are very similar to failures of earthfill dams. If levee crests slump enough to create overtopping, then rapid erosion leading to levee failure is possible.

Earthquake-induced failures of concrete or steel water storage reservoirs for potable water system are also possible.

For facilities behind levees or with dams or reservoirs upstream , a seismic risk assessment should include evaluation of possible inundation of the facilities from dam, levee or reservoir failures (see the Dam Safety Hazard Profile for more information on their impacts).

Tsunamis and Seiches

Tsunamis, which are sometimes incorrectly referred to as “tidal waves,” result from earthquakes that cause a sudden rise or fall of part of the ocean floor. Such movements may produce tsunami waves, which have nothing to do with the ordinary ocean tides. Tsunamis may also be generated by undersea landslides, by terrestrial landslides into bodies of water, and by asteroid impacts. However, earthquakes are the predominant cause of tsunamis.

In the open ocean, far from land and in deep water, tsunami waves may be only a few inches high and thus be virtually undetectable, except by special monitoring instruments. These waves travel across the ocean at speeds of several hundred miles per hour. When such waves reach shallow water near the coastline, they slow down and can gain great heights.

Tsunamis affecting the Washington coast can be produced from very distant earthquakes off the coast of Alaska or elsewhere in the Pacific Ocean. For such tsunamis, the warning time for the Washington coast would be at least several hours. However, interface earthquakes on the Cascadia Subduction Zone can also produce tsunamis. For such earthquakes the warning times would be very short, less than 30 minutes. Because of this extremely short warning time, emergency planning and public education are essential before such an event occurs.

Tsunamis can also be created by crustal earthquakes, such as the Seattle Fault System and the Tacoma Fault System which cross parts of Puget Sound because these earthquakes are likely to include vertical movements of the floor of the sound which will generate tsunamis. The warning times for such tsunamis would be only a few minutes.

A similar earthquake phenomenon is "seiches" which are waves from sloshing of inland bodies of waters such as lakes, reservoirs, or rivers. Seiches may result in damages to docks and other shoreline or near-shore structures. Seiches within reservoirs may also results in roof damage or, in extreme case, rupture of the entire tank with resulting flooding (see the Tsunamis Hazard Profile for more information on their impacts).

Potential Impact of Climate Change

With the advent of climate change coming into worldwide focus, it is necessary to take into account the potential effects this emerging climate crisis may have on the dangers associated with natural disasters. The research done so far indicates the potential for unusual or more frequent heavy rainfall and flooding is greater is some areas while the potential for drought is predicted in other areas. Landslide frequency is correlated with heavy rainfall and flooding events. Climate change has not necessarily been associated with increasing risk from earthquake hazards. However, general abnormalities caused by climate change, such as more unstable ground, could exacerbate the impacts of an earthquake.

Recognizing Washington's vulnerability to climate impacts, the Legislature and Governor Chris Gregoire directed state agencies in 2009 to develop an integrated climate change response strategy to help state, tribal and local governments, public and private organizations, businesses and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy*.

Over the next 50 - 100 years, the potential exists for significant climate change impacts on Washington's coastal communities, forests, fisheries, agriculture, human health, and natural disasters. These impacts could potentially include increased annual temperatures, rising sea level, increased sea surface temperatures, more intense storms, and changes in precipitation patterns. Therefore, climate change has the potential to impact the occurrence and intensity of natural disasters, potentially leading to additional loss of life and significant economic losses. Recognizing the global, regional, and local implications of climate change, Washington State has shown great leadership in addressing mitigation through the reduction of greenhouse gases.

At Risk State Facilities to Earthquake

A Hazus-MH 2.1 analysis was employed to model building losses for state-owned and state-leased facilities utilizing the Washington State Office of Financial Managements 2012 dataset of state facilities. A total of 9,975 state facilities were analyzed. These buildings have an estimated replacement value of $13,363,228,000. The combined area of the state buildings is estimated at 105,060,000 square feet. Of these buildings, 8,893 were reported as owned and 1,082 were reported as leased. Owned buildings have a combined exposure (building replacement value) of $11,858,700,000, and leased buildings have a combined value of $1,504,528,000. Owned buildings have a combined area of 93,425,000square feet, and leased buildings have a combined area of 11,635,000 square feet.

The OFM data did contain data gaps that needed to be addressed in order to perform the Hazus-MH analysis. Most critically, building type and building replacement value needed attention. For building type, it was assumed that all structures were one story and constructed of wood. Regarding building replacement value, there were both missing and erroneous data in the OFM data. Therefore, 2012 R.S. Means Facilities Construction Cost data was used to determine building replacement value using a combination of the building occupancy (Hazus classification of Government buildings (GOV1)), existing building square footage, year built and the assumed building type. From this updated building inventory, the Advanced Engineering Building Module (AEBM) was used to model each building.

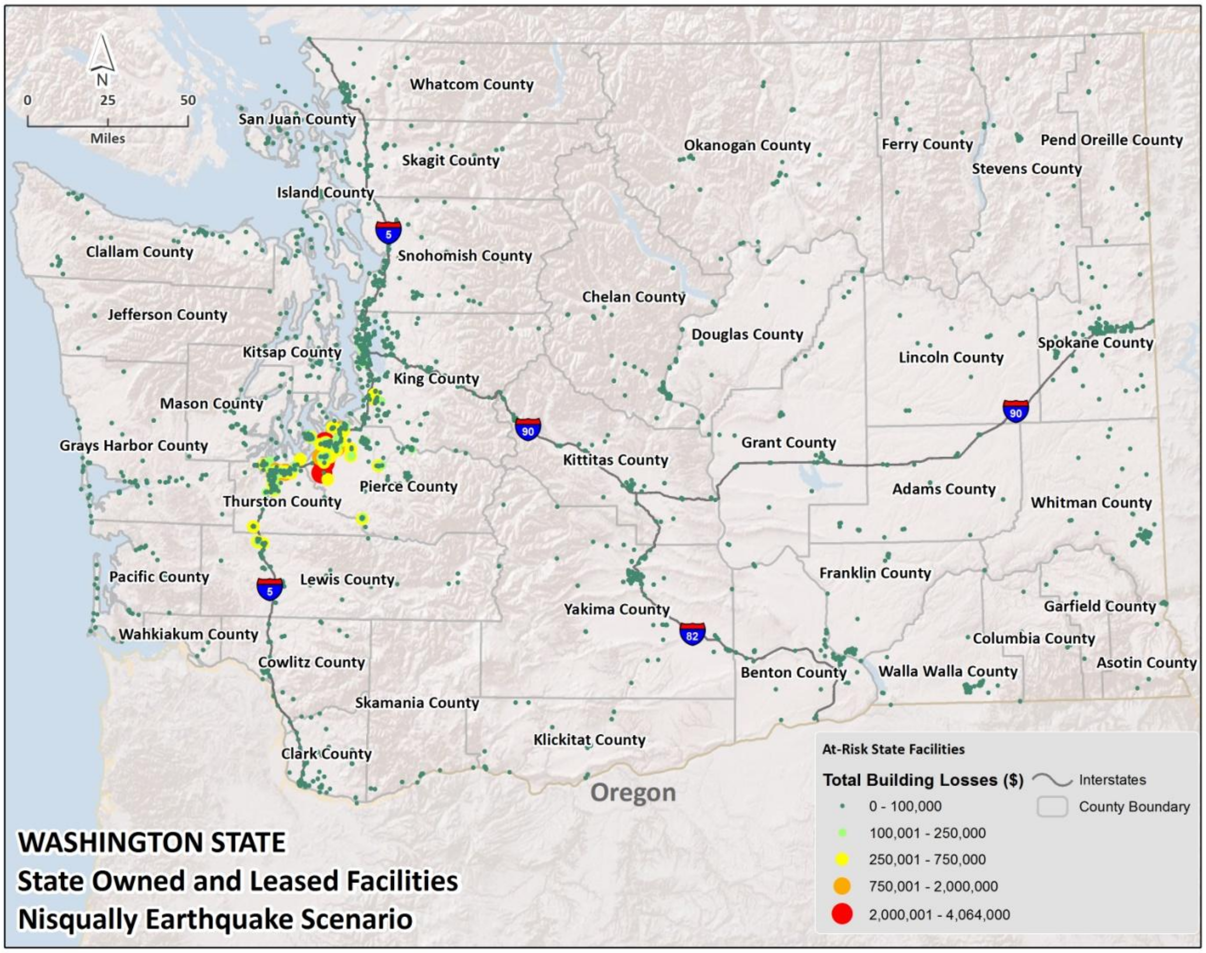
The AEBM is a Hazus-MH component that performs a detailed earthquake analysis and facilitates a site-specific building loss estimation analysis for damages and losses for each building in an inventory. There are many advanced functions, including the ability to input user-specified hazard maps, override the default building fragility curves or create your own building profiles. In this case, an AEBM inventory was developed outside of Hazus using the 2012 OFM dataset of state leased and owned facilities. This dataset was then defined in Hazus as the AEBM Inventory. A set of AEBM Profiles were then entered in Hazus for all possible building occupancies, types and earthquake design level combinations. The AEBM Profiles describe an extensive set of building performance characteristics, including damage and loss function parameters. Each building in the AEBM Inventory is then linked to one of the created AEBM Profiles.

After the AEBM Inventory and Profiles were developed, the Hazus Earthquake model was employed to generate building losses based on certain scenario earthquakes, or an earthquake with a specified magnitude and location. The resulting loss estimate generally will describe the scale and extent of damage that may result from a potential earthquake. Quantitative estimates of losses were then reported in terms of direct costs for repair and replacement of damaged buildings.

The first scenario earthquake (deterministic hazard) that was run was the February 28, 2001, Nisqually earthquake event which a Magnitude 6.8. Similar to the methodology employed for Average Annualized Losses above, two user-supplied data layers for liquefaction and soil class were added to Hazus-MH to more accurately model the effects of the earthquake at each site-specific state facility. These maps allow Hazus-MH to model the conditions present at each of the building sites.

The Nisqually M6.8 earthquake resulted in $122,589,000 potential total building losses to the 9,975 state owned facilities. Of this $90,719,000 were total building losses to the 8,893 state owned buildings and $31,871,000 were total building losses to 1,082 state leased facilities. As a percentage this represents a loss ratio of 0.91 percent of total state facility exposure (including .68 percent for state owned buildings and 0.24 percent for state leased buildings). Figure 5.4-18 below shows an overview of buildings and their associated losses.

Figure 48. State Facility Hazus-MH Earthquake Losses



Earthquake Hazard Profile Appendix A

Utilizing Enhanced Hazus-MH Input Data

It is important to note that the default Hazus-MH inventory datasets are not current to calendar year 2013. This is crucial to understand because any of the loss estimates that are generated by a Hazus-MH analysis will be portrayed with out-of-date information. As such, the losses may not be accurate to current building replacement costs or may not accurately reflect present-day population from which Hazus-MH estimates building square foot totals by tract and by block. At the time this plan was completed (May 2013), Hazus-MH version 2.1 software utilized U.S. Census 2000 data as the default primary geographic unit of analysis. To quantify building and demographic distribution across Census block and tracts, Hazus-MH uses Census 2000 data for RES1 and RES2; Building replacement costs were derived from Means Square Foot Costs 2002, for Residential, Commercial, Industrial, and Institutional buildings; to calculate business economic losses, aggregated information on total number of employees, total annual sales and total square footage by census tract is provided by 2006 Dunn and Bradstreet. Much of this default data can be enhanced with more current or local data through the use of FEMA's Comprehensive Data Management System (CDMS).

Comprehensive Data Management System (CDMS) can be used to update a variety of Hazus-MH inputs using local data (such as tax assessor or regional planning data). CDMS is a complementary tool to Hazus-MH. This software streamlines the inventory update process, allowing a user to update the entire statewide dataset with Hazus-MH, as opposed to a single study region. This permits for repeated analysis and the creation of new study regions with updated Hazus inventory. There are two main areas of Hazus-MH inventory that can be updated via CDMS. These are aggregate data sets (such as building values and counts) and site-specific data sets (Such as essential facilities. Unfortunately, local data could not be fully updated into Hazus for this plan update, but some improvements were made.

The Washington State Hazard Mitigation Plan was able to benefit from work coordinated by the Washington Hazus User Group (WAHUG). The WAHUG coordinated and completed the local data updates for the state GBS geodatabases utilizing CDMS. Local data from these counties was used to replace the default Hazus-MH data, therefore providing a more accurate and representative loss estimation. The following counties were updated using local data: Snohomish, September, 2010; Yakima, June, 2010; Lewis, June, 2010; Grays Harbor, June, 2010; and Cowlitz, June, 2010. Hazus-MH default data was used in Washington's 34 other counties. These enhanced datasets were used for the statewide General Building Stock (GBS) Average Annualized Loss (AAL) analysis in the five counties.

It is likely that future version of Hazus-MH will use 2010 or newer Census data as a default. Until then it is advisable that in any future Hazus-MH analysis technicians attempt to use the most current data available.

Following are examples of sources of inventory data that can be accessed to enhance the Hazus building data:

Locations of government facilities, ex. military installations and government offices
Databases of hazardous buildings, Tax assessor's files
School district or university system facilities
Databases of fire stations or police stations

Databases of historical buildings
Databases of churches and other religious facilities
Postal facilities (ATC-26, 1992)
Hospitals (The AHA Guide of the American Hospital Association; ATC-23A, 1991A)
Public and private utility facility databases
Department of transportation bridge inventory
Dun and Bradstreet database of business establishments
Insurance Services Office databases used for fire assessment of large buildings

Updating the Washington state-owned facilities for use in a User Defined Facilities (UDF) or in an Advanced Engineering Building Module (AEBM) analysis is important as well. In a UDF analysis User-defined facilities are those facilities, other than essential facilities or high potential loss facilities, which the user may wish to analyze on a site-specific basis.

Critical pieces of data that must be collected are:

Building Type (wood, steel, masonry, etc.)
Building Replacement Value
Building Contents Value
Building Occupancy Type
Floor Area
Number of Stories
Latitude and Longitude
Year Built

For detailed descriptions and Hazus-MH accepted values and domains please refer to the CDMS Data Dictionary.

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Flood

	Frequency	50+ yrs	10-50 yrs	1-10 yrs	Annually
	People	<1,000	1,000-10,000	10,000-50,000	50,000+
	Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
	Environment	<10%	10-15%	15%-20%	20%+
	Property	<$100M	$100M-$500M	$500M-$1B	$1B+
Flood	Hazard scale	< Low to High >			

Risk Level

Frequency – Flooding occurs in Washington on an annual basis.

People – Several U.S. floods have claimed lives, averaging 95 fatalities per year over a 30-year average.[95]

Economy – During a flooding event the local economy can suffer severely, which in turn can result in an impact to the overall economy in the state of Washington.

Environment – Although the environment can suffer irreversible damage due to a flooding event, the type of damage does not meet the threshold for this category.

Property – Disaster assistance for the 2012 floods in Washington were over an estimated $40 million dollars. Between 2004 and 2011 (as of January 31, 2012) Washington State had received $352 million in federal disaster assistance (combined hazards).[96] With continued growth of industry and towns in and around these areas, property damage is estimated to rise with each subsequent flood.

HIVA Risk Classification for Flood is 2A (2nd highest) or Mitigation to Reduce Risk is Required.

Overview –The State of Washington Department of Ecology created a document titled, “Washington State Watershed Risk Assessment,” that provides risk ranking for each watershed in the State where FEMA Flood Insurance Rate Map data were available. The report analysis considers population density, NFIP policies and claims, and floodplain area. The Lower Skagit, Puget Sound, and Strait of Georgia watersheds ranked highest in risk. The complete document can be found in Appendix B of this profile.

Summary

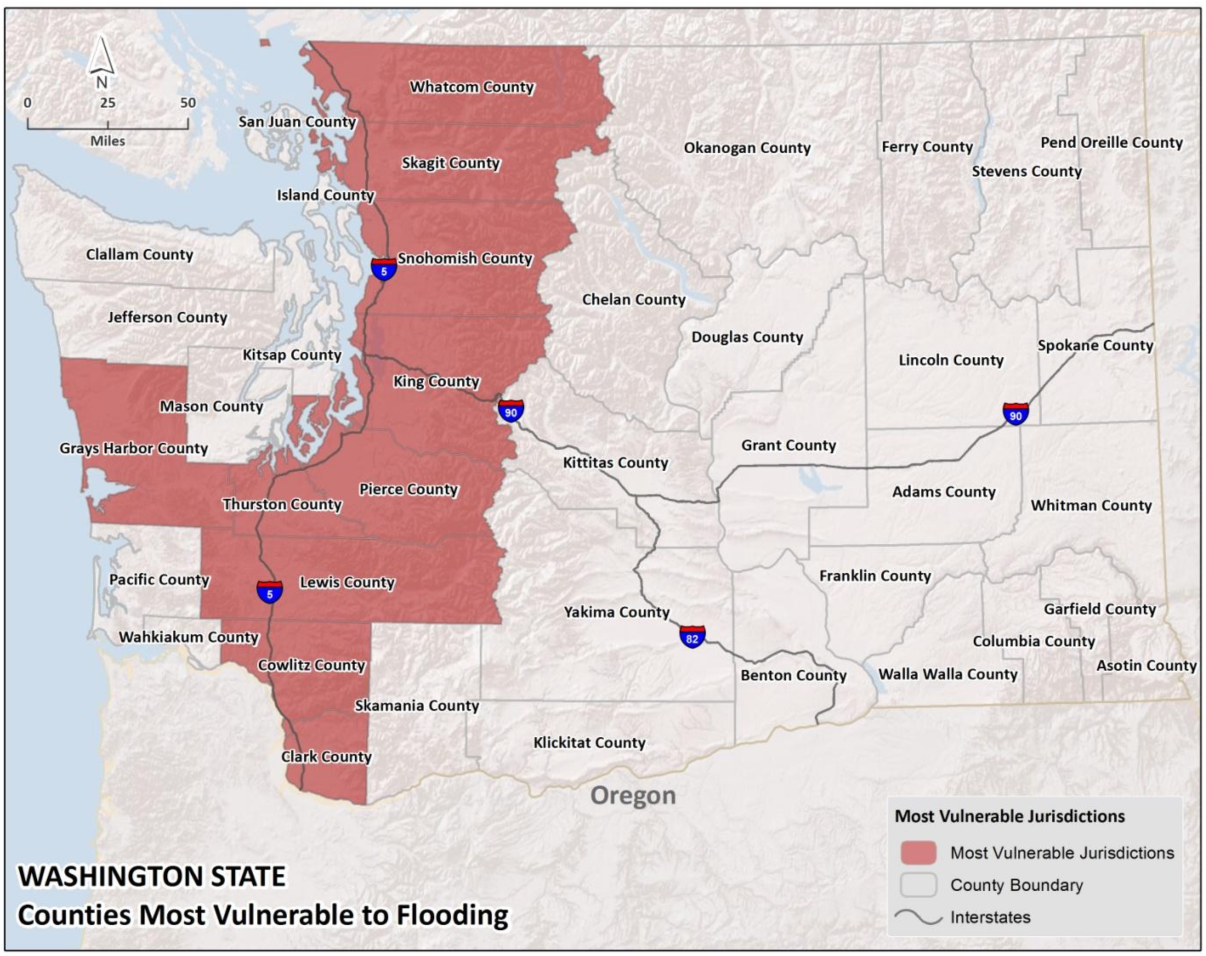
The Hazard – Flooding, the overflow of water onto normally dry land (usually a river's floodplain) due to abnormal or excessive rainfall and associated runoff, is the most prevalent natural hazard facing Washington State residents.

Previous Occurrences – Washington State has a long history of damaging floods, including the 1948 (Vanport) flood; the November 1990 back-to-back floods (Veterans Day and Thanksgiving); and February 1996 event- the most widespread flooding in the State's history, and the January 2012 event – the flood of record on some rivers. These three floods are included in the National Weather Service's list of the Top Ten Washington State Weather Events in the 20th Century. Since 1956, Washington State has received 32 Presidential Disaster Declarations for flooding with each county in the State receiving at least one declaration during this period.

Probability of Future Events – Based on presidential disaster declarations, the approximated recurrence interval for the state is a major flood event every two years. County level estimates ranged from 2 year to 11-year intervals.

Jurisdictions at Greatest Risk – Western Washington is at the greatest risk for flooding, encompassing 10 counties within the Puget Sound Basin and along the Pacific Coast as shown in the figure below (also Figure 16 at the end of this document).

Figure 49 Hazard Area Map



The Flood Hazard [97, 98]

The National Flood Insurance Program defines flood as, "A general and temporary condition of partial or complete inundation of two or more acres of normally dry land area or of two or more properties (at least one of which is the policyholder's property) from:

Overflow of inland or tidal waters; or

Unusual and rapid accumulation or runoff of surface waters from any source; or

Mudflow (liquid and flowing mud moving across surface); or

Collapse or subsidence of land along the shore of a lake or similar body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels that result in a flood as defined above."

Floods cause loss of life and damage to structures, crops, land, flood control structures, transportation infrastructure (roads and bridges) and utilities. Floods also cause erosion and landslides (including mudslides or mudflows), and can transport debris and toxic products that cause secondary damage. Flood damage in Washington State exceeds damage by all other natural hazards.

There have been 32 Presidential Major Disaster Declarations for floods in Washington State from 1956 through July 2012. Every county has received a Presidential Disaster Declaration for flooding. While not every flood creates enough damage to merit a declaration, most are severe enough to warrant intervention by local, state or federal authorities.

Between 1978 and January 2013, FEMA has paid out over $37 billion in losses on significant flood events (one with more than 1,500 losses). These funds are used repair public facilities, help individuals recover from flood disasters, and pay for measures to prevent future flood damage.[99] This equates to over a billion dollars annually. Overall flood losses would far exceed this figure. A University of Colorado study found that average annual flood damages in the U.S. are $2.41 billion.[100] The National Flood Insurance Program found that flood insurance claims alone totaled over $2.9 billion annually from 2002 to 2011. While money is made available for mitigation, the amount varies annually and does not rival the amount spent annually on disaster relief. Some studies have shown that for every $1 spent on mitigation, over $3 is saved on disaster relief assistance.

The magnitude of most floods in Washington depend on the particular combinations of intensity and duration of rainfall, pre-existing soil conditions (e.g., was the ground wet or frozen before the storm), the size of the watershed, elevation of the rain or snow level, and amount of snow pack. Man-made changes to a basin also can affect the severity of floods.

Although floods can happen at any time during the year, there are typical seasonal patterns for flooding in Washington State, based on the variety of natural processes that cause floods:

- Heavy rainfall on wet or frozen ground, before a snow pack has accumulated, typically cause fall and early winter floods.
- Rainfall combined with melting of the low-elevation snow pack typically cause winter and early spring floods. Of particular concern is the so-called Pineapple Express, a warm and wet flow of subtropical air originating near Hawaii which can produce multi-day storms with copious rain and very high freezing levels.
- Late spring floods in Eastern Washington result primarily from melting of the snow pack.

- Thunderstorms typically cause flash floods during the summer in Eastern Washington; on rare occasions, thunderstorms embedded in winter-like rainstorms cause flash floods in Western Washington.

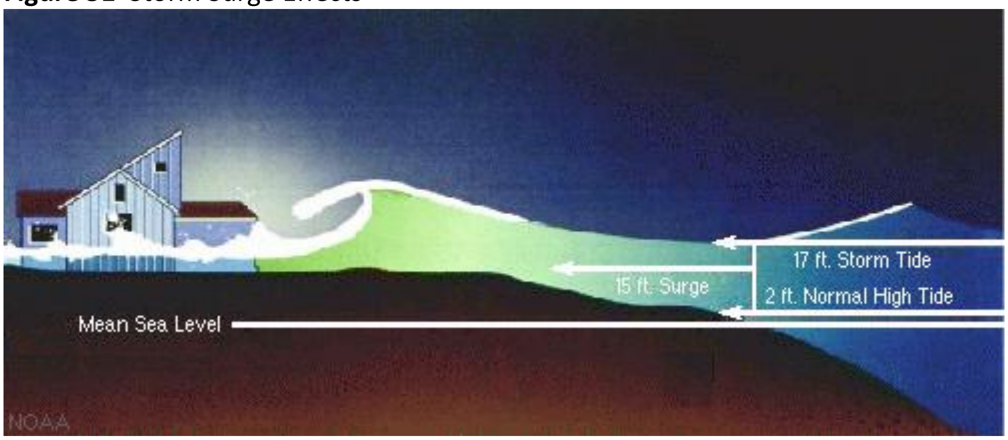
Washington State is subject to flooding from several different flood sources:
Overbank flooding from rivers and streams,
Coastal storm surge flooding,
Local stormwater drainage flooding, and
Flooding from failures of dams, reservoirs or levees.
Other flood source - subsidence, tsunamis and seiches

Overbank flooding from rivers and stream occurs throughout Washington, most commonly from winter storms with heavy rainfall from November to February. Flood events with significant contributions from snowmelt are may also occur during the spring snowmelt season. Snowmelt may be an important contribution to flooding for watersheds with high enough elevations to have significant snowfalls. Although less common, overbank flooding can also occur at any time of the year. The severity of overbank flooding depends primarily on flood depth. However, other factors such as flood duration, flow velocity, debris loads, and contamination with hazardous materials also significantly impact the severity of any given flood event. Overbank flooding can be very severe and affect broad geographic areas. Figure 1 below shows flooding along the Chehalis River in 2007.

Figure 50 Flood Event in Centralia and the Unincorporated Areas Surrounding Centralia, Washington – December 2007[101]

Coastal storm surge flooding affects low elevation areas along the coasts of the Pacific Ocean, Puget Sound and Strait of Juan de Fuca and is most common from winter storm events, generally from November through February. Coastal flooding results from the combination of storm-driven surges and daily tides. Maximum flooding occurs when the peaks of storm-driven surges coincide with high tides. The severity of coastal flooding depends not only on flood depths but also on wave effects and debris impacts. Wave pounding exerts substantial forces on structures and extended ponding by frequent waves may destroy structures not designed to withstand wave forces. Wave action may also destroy structures by erosion scour that undermine foundations. Debris impacts may greatly increase damages for a given flood depth. Figure 2 illustrates storm surge effects.

Figure 51 Storm Surge Effects



Source: NOAA

Coastal flood events are expected to become more frequent and more severe in the future because of global warming and sea level rise. Current consensus estimates[102] by climate scientists are that sea level may gradually rise by about 1.4 to 2.0 meters (4.6 to 6.2 feet) over the next hundred years. Sea level rise is also expected to exacerbate beach erosion which may further increase flooding potential in coastal areas.

Storm water drainage flooding, which is sometimes referred to as urban flooding, occurs when inflows of storm water exceed the conveyance capacity of a local storm water drainage system. The drainage system overflows, resulting in water ponding in low lying areas. This type of flooding is generally localized, with flood depths than may range from a few inches to several feet.

Failures of dams, reservoirs for potable water systems or levees results in flooding areas downstream of dams and reservoirs or behind levees. Failures of major dams operated and regulated by state or federal agencies are possible, but unlikely because these dams are generally well-designed and well-maintained. However, failures of smaller dams maintained by local governments, special districts or private owners are more common.

Failures of reservoirs for potable water systems occur, especially from earthquakes. These reservoirs typically have much smaller storage volumes than dams, so flooding from failures is generally localized. Similar flooding may occur from failures of large diameter water pipes.

Levee failures before overtopping may occur at any time, not only during high water events but also under normal non-flood conditions. There are numerous causes for such failures, including scour, foundation failures, under-seepage, through-seepage, animal burrows, and others. Failures of major levees, such as those along the Columbia River are possible, but unlikely because such levees are generally well-designed and well-maintained. Failures of smaller levees maintained by local governments, drainage districts, irrigation districts or private owners are more common.

Flooding from other sources may also occur, including subsidence, tsunamis and seiches. Major earthquakes on the Cascadia Subduction Zone are expected to result in coastal subsidence of several feet. This subsidence will result in flooding of low elevation areas. Further details about earthquakes on the Cascadia Subduction Zone are provided in the Earthquake Hazard Profile.

Cascadia Subduction Zone earthquakes will also generate tsunamis which will cause widespread inundation and heavy damage for low-elevation areas along in coastal areas on the Pacific Ocean and Puget Sound. Tsunamis within Puget Sound may also be generated by earthquakes on the Seattle Fault Zone or the Tacoma Fault Zone. Earthquakes may also generate seiches in inland bodies of water. Seiches, which are waves from sloshing of water, may result in inundation and significant damages to harbor and dock facilities as well as buildings at low elevations near the shoreline. Further details about tsunamis and seiches are provided in the Tsunami Hazard Profile.

Location of Flooding
Many rivers in Western Washington typically flood every two to five years; damaging flood events occur less frequently. These include rivers flowing off the west slopes of the Cascade Mountains (Cowlitz, Green, Cedar, Snoqualmie, Skykomish, Snohomish, Stillaguamish, Skagit, Nisqually, Puyallup, Lewis, and Nooksack); out of the Olympic Mountains (Satsop, Elwha, Dungeness, and Skokomish); and out of the hills of southwest Washington (Chehalis, Naselle, and Willapa). Long periods of rainfall and mild temperatures are normally the cause of flooding on these streams.

Several rivers in Eastern Washington also flood every two to five years, including the Spokane, Okanogan, Methow, Yakima, Walla Walla, and Klickitat; again, damaging events occur less frequently. Flooding on rivers east of the Cascades usually results from periods of heavy rainfall on wet or frozen ground, mild temperatures, or from the spring runoff of mountain snow pack.

Eastern Washington is prone to flash flooding. Thunderstorms, combined with steep ravines, alluvial fans, dry or frozen ground, and lightly vegetated ground that does not absorb water can result in flash flooding.

All of the Pacific coastal counties, Puget Sound and Strait of Juan de Fuca coastal counties, and counties at the mouth of the Columbia River, are susceptible to wind and barometric tidal flooding.

Occasionally, communities experience surface water flooding due to high groundwater tables. This occurred dramatically during the 1996-97 winter storms. In many communities, residents outside of identified or mapped flood plains had several inches of water in basements due to groundwater seepage. These floods contaminated domestic water supplies, fouled septic systems, and inundated electrical and heating systems. Fire-fighting access was restricted, leaving homes vulnerable to fire. Lake levels were the highest in recent history, and virtually every county had areas of ponding not previously seen.

Urban areas across the state have also experienced urban or small stream flooding when a developed community's stormwater drainage system is overwhelmed by excessive rainfall and runoff from impervious surfaces such as roads and parking lots. While normally not life-threatening, such urban flooding can be very disruptive for residents. These events may increase as urban areas develop rapidly without commensurate improvements in urban drainage infrastructure.

Riverine Floodplains make up about 4.5 percent of the state's total land area based on the 1.0-percent annual chance flood modeled for this plan. These areas contain an estimated 430,000 households based on census blocks showing flooding and the population within.[3] All the homes and people who live in them are vulnerable to flood damage. Only about 25 to 35 percent of the homes in floodplains have insurance for flood losses. Uninsured homeowners face greater financial liability than they realize. For example, for a $50,000 federal disaster assistance loan at 4% interest, your monthly payment would be around $240 a month ($2,880 a year) for 30 years. Compare that to a $100,000 flood insurance premium, which is about $400 a year ($33 a month).[103] During a typical 30-year mortgage period, a home in a mapped floodplain has 26 percent chance of damage by a 100-year flood event. The same structure only has about a 1 percent chance of damage by fire.

State Floodplain Management Program
The Washington State Department of Ecology (Ecology) Floodplain Management Program plays an important role in state mitigation with respect to flooding events. Program staff assists communities in administering their local floodplain management programs, make substantial damage determinations after a flood and ensure that communities are in compliance with their local ordinances. In addition, they work to provide assistance to non-participating communities that wish to enter the National Flood Insurance Program (NFIP) and provide technical assistance to participating communities interested in enrolling in the Community Rating System (CRS). Floodplain Management staff provides technical assistance to the Washington State Hazard Mitigation Advisory Team (SHMAT) as well as mitigation staff in administering the mitigation programs and developing a repetitive loss strategy for the state. Floodplain Management staff provides training to local government and emergency management officials on floodplain management and mitigation. Ecology also developed the Floodplain Management Guidebook, which provided additional planning guidance for local jurisdictions to meet FMA planning requirements with respect to NFIP, floodplain management and mitigation planning.

In addition to the above, Ecology supports ongoing updates to existing FEMA floodplain mapping and risk reduction programs. Ecology's Floodplain Management Program has partnered with FEMA under two FEMA programs - Map Modernization and Risk MAP - in support of effective implementation of floodplain regulations and flood hazard reduction. Both of these mapping programs are discussed in detail below.

National Flood Insurance Program (NFIP)[104]
The U.S. Congress established the National Flood Insurance Program (NFIP) with the passage of the National Flood Insurance Act of 1968. NFIP allows property owners in participating communities to purchase insurance as a protection against flood losses in exchange for State and community floodplain management regulations that reduce future flood damages. Participation in the NFIP is optional, and is based on an agreement between communities and the Federal Government. If a community adopts and enforces a floodplain management ordinance to reduce future flood risk to new construction in floodplains, the Federal Government will make flood insurance available within the community as a financial protection against flood losses. This insurance is designed to provide an insurance alternative

[3] Not that all households may be not be subject to flooding. A value of 2.5 persons per household was utilized to determine number of household from the approximate population.

to disaster assistance to reduce the escalating costs of repairing damage to buildings and their contents caused by floods.

The emphasis of the NFIP floodplain management requirements is directed toward reducing threats to lives and the potential for damages to property in flood-prone areas. One key component in the Act is the restriction in place which prohibits FEMA from providing flood insurance to any individual unless the community within which the intended insured resides has adopted and enforces floodplain management regulations that meet or exceed the floodplain management criteria established within 44 Code of Federal Regulations (CFR) Part 60, *Criteria for Land Management and Use.*

As part of the NFIP, various funding opportunities are available for mitigation efforts. These funding opportunities are discussed in greater detail within the *Enhanced* portion of the SHMPH, Element Enhanced.

Two elements which must be met by all jurisdictions within the local mitigation plan is the issue of Repetitive Loss Properties and Severe Repetitive Loss properties as they relate to floods only. These are defined as:

Repetitive Loss Properties
A repetitive loss property is one for which two or more losses of at least $1,000 each have been paid by the National Flood Insurance Program (NFIP) over a rolling 10-year period.
Severe Repetitive Loss

An SRL property is a residential property that is covered under an NFIP flood insurance policy and:

(1) That has at least four NFIP claim payments (including building and contents) over $5,000 each, and the cumulative amount of such claims payments exceeds $20,000; or
(2) For which at least two separate claims payments (building payments only) have been made with the cumulative amount of the building portion of such claims exceeding the market value of the building.
(3) For both (a) and (b) above, at least two of the referenced claims must have occurred within any 10-year period, and must be greater than 10 days apart.

In addition to providing flood insurance and reducing flood damages through floodplain management regulations, the NFIP identifies and maps the Nation's floodplains. Mapping flood hazards creates broad-based awareness of the flood hazards and provides the data needed for floodplain management programs and to actuarially rate new construction for flood insurance. Recently, this mapping initiative has taken a new step toward providing a more reliable mapping system with the creation of Risk MAP (discussed in greater detail below).

The Biggert-Waters Flood Insurance Reform Act of 2012 extends the National Flood Insurance Program (NFIP) through 2017 and included several reforms included eliminating subsidized insurance rate of repetitive loss properties. Some of the changes to be implemented include[105]:
Owners of **non-primary/secondary** residences in a Special Flood Hazard Area (SFHA) will see 25 percent increase annually until rates reflect true risk – began January 1, 2013.
Owners of **property which has experienced severe or repeated flooding** will see 25 percent rate increase annually until rates reflect true risk – beginning October 1, 2013.
Owners of **business properties in a Special Flood Hazard Area** will see 25 percent rate increase annually until rates reflect true risk -- beginning October 1, 2013.

Owners of primary residences in SFHAs will be able to keep their subsidized rates unless or until:
You sell your property;
You allow your policy to lapse;
You suffer severe, repeated, flood losses; or
You purchase a new policy.
Grandfathered rates will be phased over five years

Community Rating System[106]

The National Flood Insurance Program's Community Rating System (CRS) was implemented in 1990 as a voluntary program, which recognizes and encourages community floodplain management activities that exceed the minimum NFIP standards. The National Flood Insurance Reform Act of 1994 codified the Community Rating System in the NFIP.

As a result of CRS, flood insurance premium rates are discounted to reflect the reduced flood risk resulting from the community actions meeting the three goals of the CRS:

- Reduce flood losses
- Facilitate accurate insurance rating
- Promote the awareness of flood insurance

The more a jurisdiction does in excess of NFIP standards, the more points they earn. These points are then utilized to establish the jurisdictions CRS class. There are ten CRS classes. Class one (1) requires the most credit points and gives the largest premium reduction; class 10 receives no premium reduction. For CRS participating communities, flood insurance premium rates are discounted in increments of 5%; i.e., a Class 1 community would receive a 45% premium discount, while a Class 9 community would receive a 5% discount, and as indicated above, a Class 10 is not participating in the CRS and receives no discount.

The CRS classes for local communities are based on 18 creditable activities, organized under four categories:
Public Information
Mapping and Regulations
Flood Damage Reduction
Flood Preparedness.

More information on the CRS program is available at on FEMA's website at: http://www.fema.gov/business/nfip/crs.shtm

The table below describes the credit points earned, classification awarded and premium reductions given for Washington communities in the National Flood Insurance Program Community Rating System.

Table 28. Communities Participating in the CRS and Associated CRS Class

COMMUNITY NUMBER	COMMUNITY NAME	CRS ENTRY DATE	CURRENT CLASS	% DISCOUNT FOR SFHA
530073	Auburn, City of	10/1/92	5	25
530074	Bellevue, City of	10/1/92	5	25
530153	Burlington, City of	10/1/94	5	25
530103	Centralia, City of	10/1/94	5	25

Table 28. Communities Participating in the CRS and Associated CRS Class

COMMUNITY NUMBER	COMMUNITY NAME	CRS ENTRY DATE	CURRENT CLASS	% DISCOUNT FOR SFHA
530104	Chehalis, City of	10/1/94	5	25
530024	Clark County	10/1/04	5	25
530051	Ephrata, City of	10/1/00	7	15
530200	Everson, City of	10/1/94	7	15
530140	Fife, City of	05/1/06	5	25
530166	Index, Town of	04/1/98	6	20
530079	Issaquah, City of	10/1/92	5	25
530080	Kent, City of	05/1/10	6	20
530071	King County	10/1/91	2	40
530156	La Conner, Town of	10/1/96	7	15
530102	Lewis County	10/1/94	7	15
530316	Lower Elwha Klallam Tribe	10/1/00	8	10
530331	Lummi Nation	05/1/10	8	10
530169	Monroe, City of	10/1/91	5	25
530158	Mount Vernon, City of	05/1/97	6	20
530085	North Bend, City of	10/1/95	6	20
530143	Orting, City of	05/1/08	6	20
530138	Pierce County	10/1/95	2	40
530088	Renton, City of	10/1/94	6	20
530151	Skagit County	04/1/98	4	30
535534	Snohomish County	05/1/06	4	30
530090	Snoqualmie, City of	10/1/92	5	25
530173	Sultan, City of	10/1/03	7	15
530204	Sumas, City of	10/1/93	7	15
530188	Thurston County	10/1/00	5	25
530193	Wahkiakum County	10/1/07	8	10
530067	Westport, City of	10/1/09	6	20
530198	Whatcom County	10/1/96	6	20
530217	Yakima County	10/1/07	8	10

In addition to the CRS community status provided above, data pertaining to the NFIP statistics (including policies and claims) can be found in Appendix A. The information providing above and in Appendix A provides statistical data as it relates to Washington's involvement in the NFIP during the 2013 plan update process. Information is always changing, and therefore, as local jurisdiction plans are updated, the most current data should be gathered to meet planning requirements from the Emergency Management Division, Department of Ecology, or FEMA. At present time, the facts below demonstrate the overall importance of the NFIP to the State and demonstrate the level of flooding concern. The information represents the most currently available data as of the dates referenced within each section.

Risk MAP (Risk Mapping Assessment and Planning)[107]

Risk MAP replaced the Flood Map Modernization program in 2010. Flood Map Modernization was established in 1997 to digitally update FEMA flood maps. Under the Map Moderations Program, several counties in the state were mapped, providing countywide Digital Flood Insurance Rate Maps (DFIRMs). These include:

Adams	Grays Harbor	Skagit
Clallam	Island	Snohomish
Clark	King	Spokane
Cowlitz	Kitsap	Thurston
Ferry	Lewis	Whatcom
Grant	Pierce	Yakima

FEMA's Risk MAP program takes a holistic, community-wide approach to floodplain planning activities. The purpose behind FEMA's Risk MAP Strategy is to constantly reduce losses to life and property. Flood mapping is used for risk assessments which are incorporated into mitigation plans where risk reduction measures are identified for future action. Risk MAP will identify, assess, and communicate multi-hazard risks with non-regulatory products and assessments. Washington State Department of Ecology is partnering with FEMA to implement the four fundamental strategies to Risk MAP in Washington State. The four strategies include Identify Risk, Assess Risk, Communicate Risk, and Mitigate Risk. The Risk MAP program further enhances mapping by involving communities during the assessment and planning stages, and guides and encourages communities to communicate risk to their constituents.

Ecology has developed two new floodplain management tools for open use by the public, communities, agencies, and stakeholders in the floodplains. The Washington State Coastal Atlas delivers flood hazard maps in an internet mapping application using the latest orthophotos to view floodplain at the property level. Several websites are available for more information on these references:

Coastal Atlas for Washington State: https://fortress.wa.gov/ecy/coastalatlas/

Risk MAP program in Washington State:

http://www.ecy.wa.gov/programs/sea/floods/index.html

The official FEMA Risk MAP website: http://www.fema.gov/risk-mapping-assessment-planning

Previous Occurrences

The following is a synopsis of damaging floods that occurred in this half-century from 1948 to 2012. It is not a complete history of flood events, but a sample for which documentation is readily available that shows the breadth of the flood problem in Washington.

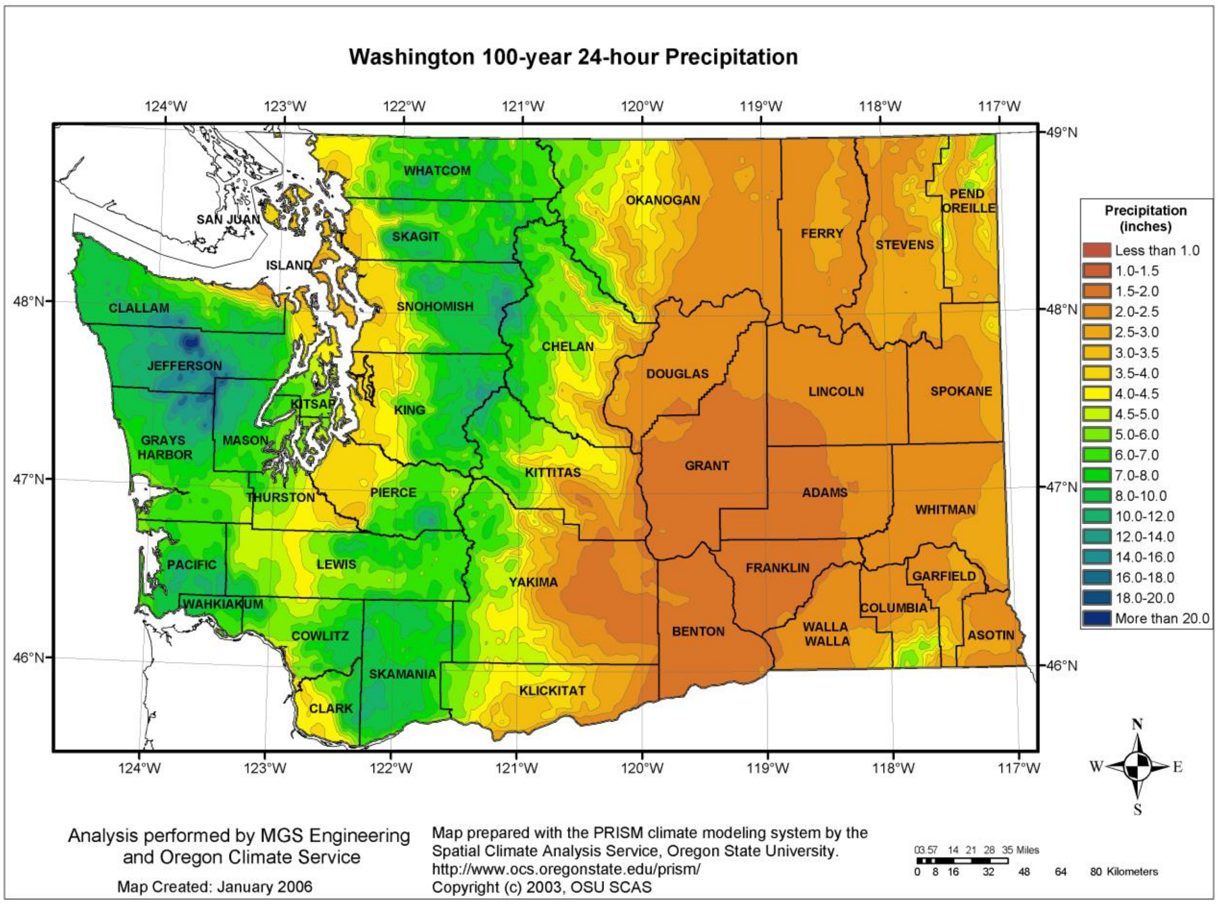
Several flood disasters described below include narratives or tables that depict projected recurrence rates for floods of the magnitude observed; information is for events and selected rivers, streams and lakes for which data is available. The probability of a flood event occurring is expressed as a percent chance that a flood of a specific magnitude will occur in any given year. For example, a flood with a 10-year recurrence rate has a 10 percent chance of occurring in any one year.

The table below demonstrates how recurrence rate translates to the chance of occurrence for the types of floods the state has experienced.

Table 29 Flood Return Intervals	Chance of Occurrence In Any Given Year
10 Years	10%
20 Years	5%
25 Years	4%
50 Years	2%
100 Years	1%
500 Years	0.2%

Map of 24-hour precipitation totals that would qualify as a 100 year event (from MGS Engineering Consultants).[108] The frequency of major flooding is well-correlated with precipitation levels. Figure 3 on the following page shows 100-year 24-hour precipitation data. The high precipitation areas, shown in blue, green and yellow on Figure 3 include all of the counties with a history of frequent major flood events.

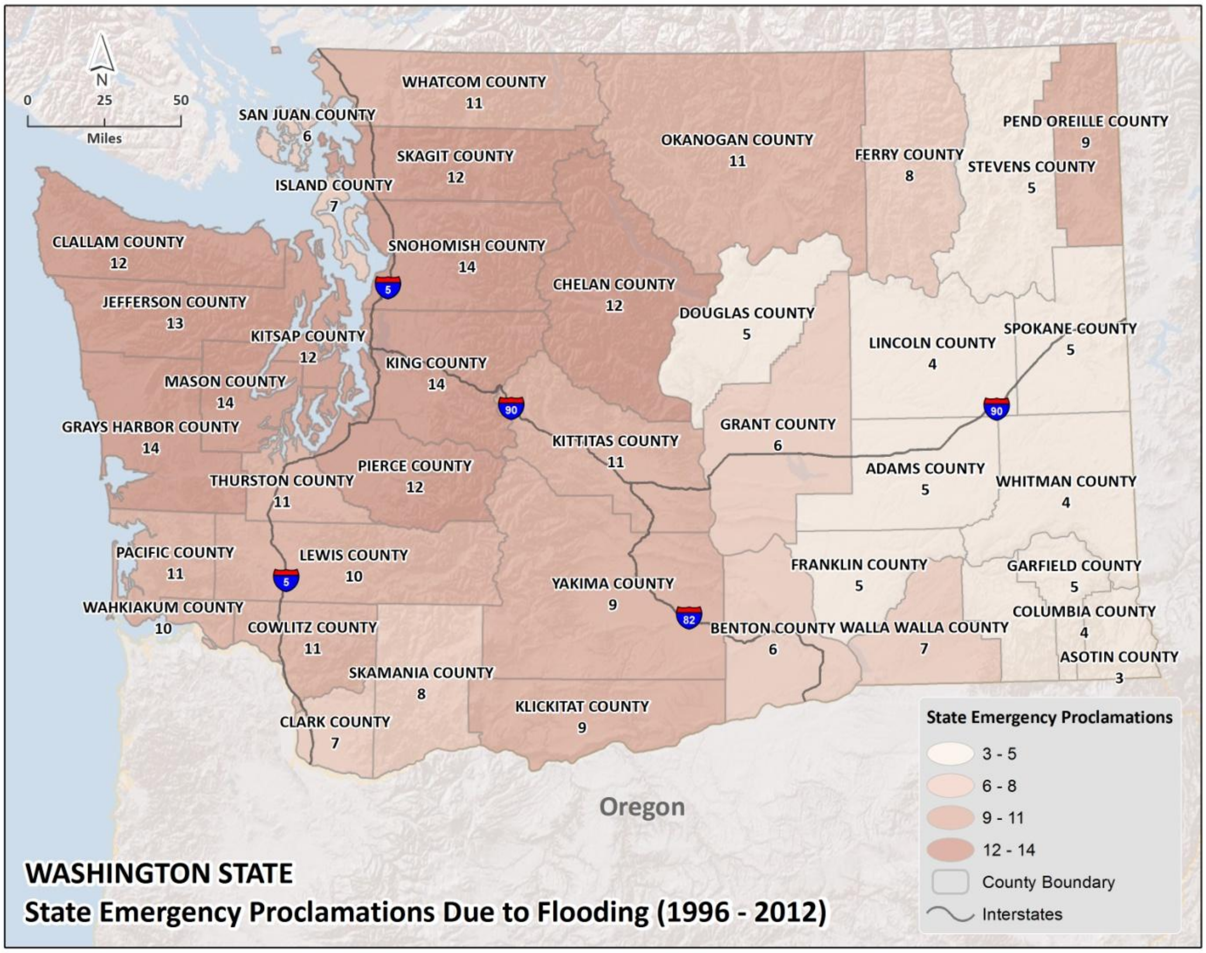
Figure 51 Washington Map of 1.0-percent Annual Chance Flood 24-hour Precipitation



For some tables below, recurrence intervals determined using data in *Magnitude and Frequency of Floods in Washington*, Department of Interior, United States Geological Survey Water-Resources Investigations Report 97-4277, 1998.

The hazard area map of Washington depicts the number of emergency declarations for each county due to flooding. Governor's Emergency Proclamations from 1996 to December 2012 were gathered, the number of declarations for each county was compiled for each year and then all declarations were totaled to generate Figure 4 below. A total of 57 state proclamations were issued including four statewide proclamations.

Figure 52 State Emergency Proclamations (1996-2012)



The following text relays several historic occurrence events including federal disaster declarations.

May-June 1948 [109]

Vanport Flood. (One of the top 10 weather events in Washington during the 20th Century, according to National Weather Service, Seattle Forecast Office). Snowmelt flooding broke lake and river records in Eastern Washington and along the Columbia River to the Pacific Ocean. The Columbia River below Priest Rapids, WA, established a new flood of record at 458.65 feet (flood stage 432.0 feet). The Methow River at Pateros, WA, established a new flood of record at 12.30 feet (flood stage 10.0 feet). The flood lasted 45 days. Vancouver, Camas, Kalama, and Longview suffered flood damage. This flood is most notable for wiping out the community of Vanport in North Portland in less than one hour as dikes along the Columbia River gave way. Vanport, America's largest wartime housing project was not rebuilt.

Recurrence interval of this Columbia River flood is projected at 30 years.[110] A number of hydroelectric dams constructed on the Columbia after this event also control flooding, reducing the probability of flooding along much of the length of the river in Washington.

January 1971
Federal Disaster (DR-314)
Snow melt in the counties of Columbia, Garfield, Grays Harbor, Lewis, Skagit, Whatcom and Yakima, combined with heavy rains, produced major flooding throughout the region.

January 1972
Federal Disaster (DR-322)
Severe storms in the counties of Asotin, Cowlitz, Grays Harbor, Lewis, Pacific, Skamania, Thurston, Wahkiakum and Whitman counties caused flooding throughout the region.

February 1972
Federal Disaster (DR-328)
Heavy rains in the counties of King, Pierce and Thurston produced major flooding throughout the area.

May-June 1972
Federal Disaster (DR – 334)
Snow melt in north-central Washington counties of Chelan, Douglas, and Okanogan, combined with heavy rains, produced major flooding on the Okanogan and Methow Rivers in Okanogan County and the Entiat River in Chelan County. All three rivers reached record flood stages. Recurrence intervals for flood levels are not available for this disaster.

January 1974
Federal Disaster (DR – 414)
Unseasonably warm temperatures (+/- 65 degrees) , along with monsoon-like rains caused extensive flooding within three states: Washington, Oregon and Idaho. The counties of Asotin, Benton, Columbia, Ferry, Kitsap, Klickitat, Lewis, Mason, Pend Oreille, Stevens, Thurston, Whitman, and Yakima were declared within the state of Washington.

December 1975
Federal Disaster (DR-492)
Unusually heavy and warm rains, together with warm, strong winds, caused flooding mainly within western Washington – Cowlitz, Grays Harbor, King, Lewis, Mason, Pierce, Skagit, Snohomish, Whatcom and Thurston Counties, but also impacted a number of eastern Washington counties: Benton, Kittitas and Yakima. This disaster was considered a statewide event. On the Snohomish River, though the discharge at Monroe was only the fifth largest (the November 25 1990 flood discharge being the largest on record), the 1975 flood produced the highest flood stage ever recorded on the Snohomish at the City of Snohomish; this stage was 34 feet, which is higher than both the January 2009 and November 2006 floods. Snohomish River flooding in the 1975 flood was (in)famous for the drowning of over 2,000 head of cattle, which spurred the concept of establishing "critter pads" in many western Washington floodplains.

According to estimates of the Federal Disaster Assistance Administration of HUD (FEMA not being created until 1979), there was $35 million in losses during this flood. These losses were estimated to include $17 million in public losses, $13 million in agricultural losses and $5 million in private property losses (later estimates ranged up to $70 million in damages).

December 1977[111]
Federal Disaster (DR-545)
Severe storms, mudslides, high tides and flooding categorized this event as a very large Statewide flood that included a record 16 counties, both in western (10 counties) and eastern (6 counties) Washington. Impacted were: Benton, Clark, Cowlitz, Garfield, Grays Harbor, King, Kittitas, Klickitat, Lewis, Pacific, Pierce, Snohomish, Thurston, Wahkiakum, Whitman and Yakima Counties.

This event closed both I-90 and I-5 due to slides and high water on the road surface, trapped two freight trains due to washout of the tracks, caused four deaths and left thousands homeless. Every major western Washington river experienced some flooding, and there was serious flooding on the Naches and Yakima Rivers in eastern Washington.

Estimates indicated damages to be in the tens of millions of dollars. According to a December 4, 1977 news article in the Seattle Times, Senator Henry Jackson was quoted as saying “this year’s flood is clearly more severe than the floods of 1975, which caused $70 million in damage”.

December 1979
Federal Disaster (DR-612)
Storms, high tides, mudslides and flooding impacted the counties of Clallam, Grays Harbor, Jefferson, King, Mason, Skagit, Snohomish and Whatcom. This event produced a record rainfall of 12.7 inches; normal rainfall for the same time of year at SeaTac was 5.94 inches. The flood event started on December 15th, with most rivers peaking between December 17 and 20, 1979.

Although most of the damages were on streams that flowed out of the Cascades, flooding on these streams were mostly 5-10 year floods. Flooding was much more severe on the Olympic Peninsula, though damages were less severe because there were no large populations along these rivers. The Bogachiel, Calawah, and Hoh Rivers were 50-year floods or greater. A total damage figure for this event was approximately $8 million, and the declaration was only for individual assistance only.

December 1982 [112]
Federal Disaster (DR-676)
Disaster assistance provided – $1.7 million. Small Business Administration loaned $1 million to home and business owners for damages. Flooding, severe storm, and high tide affected Whatcom County. Four persons injured, 122 people evacuated; 129 homes and 113 businesses damaged; $1.7 million in public facility damage. Recurrence intervals for flood levels are not available for this disaster.

January 1986 [113]
Federal Disaster (DR-757)
Flooding and severe storms in Clallam, Jefferson, and King Counties caused $5 million in damage to public facilities. Recurrence intervals for flood levels are not available for this disaster.

February 1986 [114]
Federal Disaster (DR-762)
Flooding, heavy rainfall, and mudslides in Cowlitz County caused $5 million in damage to public facilities and private property. Recurrence interval of the Cowlitz River flood at Castle Rock projected at 2 years.

November 1986 [115]
Federal Disaster (DR-784)

Stafford Act disaster assistance provided – $1.9 million.
Heavy rainfall, mild temperatures, and low-elevation snowmelt generated major floods on the Chehalis, Skookumchuck, Skykomish, Snoqualmie, and Snohomish Rivers. Less severe flooding occurred on the Satsop, Skokomish, Cedar, Stillaguamish, Skagit, and Nooksack Rivers. Flooding occurred in Cowlitz, King, Lewis, Pacific, Snohomish, and Wahkiakum Counties. Two deaths, $11 million in private property damage, and $6 million in public facility damage. One-hundred twenty homes in the City of Snoqualmie were evacuated. Two-hundred eighty homes and businesses were flooded in Lewis County; impacts included a major hazardous materials spill (pentachlorophenol) from an underground storage tank and Lewis County had fairgrounds under nine feet of water. Numerous levees overtopped and damaged throughout flooded counties.

Table 30 Disaster #784, Flood Recurrence Interval This Event, Selected Rivers

River (County)	Flood Recurrence Interval	Chance of Annual Occurrence
Snoqualmie (King County)	15 – 20 Years	4 – 6%
Skykomish (Snohomish County)	10 – 25 Years	4 – 10%
Snohomish (Snohomish County)	5 – 15 Years	6 – 20%
Puyallup (Pierce County)	40 – 45 Years	~2%
Chehalis (Grays Harbor County)	45 – 50 Years	~2%

March 1989 [116]
Federal Disaster (DR-822)

Stafford Act disaster assistance provided – $3.8 million. Flooding and heavy rainfall affected Douglas, Okanogan, Stevens, and Whitman Counties. Roads and utilities heavily damaged in four rural counties. Mud from flooding impaired the city of Bridgeport's sewage treatment facility for months. Total damage to public facilities was $2 million. Recurrence intervals for flood levels are not available for this disaster.

January 1990 [117]
Federal Disaster (DR-852)

Stafford Act disaster assistance provided – $17.8 million. Flooding occurred on the Chehalis, Skookumchuck, and Deschutes Rivers as heavy rainfall and severe storms affected Benton, Grays Harbor, King, Lewis, Pierce, Thurston, and Wahkiakum Counties. Four deaths; $16 million in damages to public facilities and $6 million private property damage. Hundreds of people evacuated, several hundred homes and businesses damaged or destroyed. Chehalis hospital isolated by floodwaters; several nursing homes evacuated. Interstate 5 in Chehalis closed for several days, covered by 3 to 5 feet of water. Recurrence intervals for flood levels are not available for this disaster.

November 1990[118, 119]
Federal Disaster (DR-883).

Stafford Act disaster assistance provided – $57 million. This was one of the top 10 weather events in Washington during the 20th Century, according to National Weather Service, Seattle Forecast Office.

Severe storms and flooding occurred during Veteran's Day and Thanksgiving weekend holidays in Chelan, Clallam, Grays Harbor, Island, Jefferson, King, Kitsap, Kittitas, Lewis, Mason, Pacific, Pierce, San Juan, Skagit, Snohomish, Thurston, Wahkiakum, Whatcom, and Yakima counties. Widespread, major flooding occurred in both Western and Eastern Washington. Rivers with major flooding were the Skagit and Nooksack Rivers. The Thanksgiving weekend floods set record flood stages on the Naselle, Willapa, Hoh, Calawah, Dungeness, Skokomish, Cedar, Skykomish, Snoqualmie, Snohomish, Stillaguamish, Chiwawa, Wenatchee, Elwha, and Klickitat Rivers. Two people died; more than 500 cattle perished. Damage estimated at $250 million. Many levees overtopped and damaged. Hundreds of homes evacuated; much of the city of Snoqualmie evacuated. Thousands of acres of farmland flooded and evacuated; on Fir Island, Skagit County, 167 homes were flooded by 8 feet of water; on Eby Island, Snohomish County, only people with elevated homes stayed.

Table 31 Disaster #883, Flood Recurrence Interval This Event, Selected Rivers

River (County)	Flood Recurrence Interval	Chance of Annual Occurrence
Skagit (Skagit County)	50 Years	2%
Snohomish (Snohomish County)	50 – 100 Years	1 – 2%
Nooksack (Whatcom County)	100 Years	1%

December 1990
Federal Disaster (DR-896).

Stafford Act disaster assistance provided – $5.1 million. Floods, storms, and high winds affected the counties of Island, Jefferson, King, Kitsap, Lewis, Pierce, San Juan, Skagit, Snohomish, and Whatcom. Recurrence intervals for flood levels are not available for this disaster.

November – December 1995 [120]
Federal Disaster (DR-1079).

Stafford Act disaster assistance provided – $45.9 million. Small Business Administration disaster loans approved - $4.3 million.

Flooding and wind in the counties of Chelan, Clallam, Clark, Cowlitz, Grays Harbor, Island, Jefferson, King, Kittitas, Lewis, Mason, Pacific, Pierce, Skagit, Snohomish, Thurston, Wahkiakum, Whatcom, and Yakima. More than 850 homes damaged or destroyed; one death reported.

Table 32 Disaster #1079, Flood Recurrence Interval This Event, Selected Rivers[121]

River (County)	Flood Recurrence Interval	Chance of Annual Occurrence
Naselle near Naselle (Pacific County)	10 Years	10%
Quinault at Quinault Lake (Grays Harbor County)	10 Years	10%
American River near Nile (Yakima County)	10 Years	10%
Snoqualmie, multiple locations (King County)	10 – 25 Years	4 – 10%
Willapa near Willapa (Pacific County)	15 Years	7%

Table 32 Disaster #1079, Flood Recurrence Interval This Event, Selected Rivers[121]

River (County)	Flood Recurrence Interval	Chance of Annual Occurrence
Snohomish (Snohomish County)	20 Years	5%
Cedar, multiple locations (King County)	20 – 40 Years	~2 – 5%
Nooksack near Ferndale (Whatcom County)	25 Years	4%
Sauk near Sauk (Skagit County)	25 Years	4%
Skagit, multiple locations (Skagit County)	50 – 75 Years	~2%
Cowlitz, multiple locations (Cowlitz County)	50 – 100 Years	1 – 2%
Nisqually at LaGrande (Thurston County)	50 Years	2%
Puyallup at Alderton (Pierce County)	100 Years	1%
Stehekin at Stehekin (Chelan County)	100 Years	1%
Wenatchee, multiple locations (Chelan County)	100 Years	1%

February 1996 [122, 123]

Federal Disaster (DR-1100).

Stafford Act disaster assistance provided – $113 million. Small Business Administration disaster loans approved - $61.2 million. This was one of the top 10 weather events in Washington during the 20th Century, according to National Weather Service, Seattle Forecast Office.

Heavy rainfall, mild temperatures and low-elevation snowmelt caused flooding in Adams, Asotin, Benton, Clark, Columbia, Cowlitz, Garfield, Grays Harbor, King, Kitsap, Kittitas, Klickitat, Lewis, Lincoln, Pierce, Skagit, Skamania, Snohomish, Spokane, Thurston, Wahkiakum, Walla Walla, Whitman and Yakima counties, and the Yakima Indian Reservation. Record floods occurred on the Columbia, Snoqualmie, Cedar, Chehalis, Nisqually, Skookumchuck, Klickitat, Skokomish, Cowlitz, Yakima, Naches, Palouse and Walla Walla Rivers, and Latah Creek. The table below shows how frequently flooding of the magnitude observed in this event will occur on selected rivers and streams for which data is available.

Table 33 Disaster #1100, Flood Recurrence Interval This Event, Selected Rivers and Streams[124]

River / Stream (County)	Flood Recurrence Interval	Chance of Annual Occurrence
Ahtanum Creek (Yakima County)	20 Years	5%
Deschutes River (Thurston County)	25 Years	4%
South Prairie Creek (Pierce County)	37 Years	3%
Newaukum River (Lewis County)	90 Years	~1%
Chehalis River (Thurston, Lewis Counties)	90 – 100 Years	1%
Newaukum Creek (King County)	100 Years	1%
Puyallup River (Pierce County)	100 Years	1%

Mudslides occurred throughout the state causing significant impacts to transportation infrastructure including highways and rail corridors. Three deaths, 10 people injured. Nearly 8,000 homes damaged or destroyed. Traffic shut down for several days both east and west, and north and south, along major state highways. Snow avalanches closed Interstate 90 at Snoqualmie Pass. Mudslides in Cowlitz County and flooding in Lewis County closed Interstate 5. Damage throughout the Pacific Northwest estimated at $800 million.

December 1996 - January 1997 [125]
Federal Disaster (DR-1159).

Stafford Act disaster assistance provided – $83 million. Small Business Administration loans approved – $31.7 million.

Saturated ground combined with snow, freezing rain, rain, rapid warming and high winds within a five-day period to cause flooding. Impacted counties – Adams, Asotin, Benton, Chelan, Clallam, Clark, Columbia, Cowlitz, Douglas, Ferry, Franklin, Garfield, Grant, Grays Harbor, Island, Jefferson, King, Kitsap, Kittitas, Klickitat, Lewis, Lincoln, Mason, Okanogan, Pacific, Pend Oreille, Pierce, San Juan, Skagit, Skamania, Snohomish, Spokane, Stevens, Thurston, Walla Walla, Whatcom, Whitman, and Yakima. Significant urban flooding occurred north of Pierce County; significant river flooding occurred south of Pierce County; severe groundwater flooding took place in Pierce and Thurston Counties. The table below shows how frequently flooding of the magnitude observed in this event will occur on selected rivers and lakes for which data is available.

Table 34 Disaster #1159, Flood Recurrence Interval, Selected Rivers and Lakes[126]

River / Lake (County)	Flood Recurrence Interval	Chance of Annual Occurrence
Chehalis River (Grays Harbor County)	10 Years	10%
Klickitat River (Klickitat County	10 Years	10%
Palouse River (Whitman County)	10 Years	10%
Skookumchuck River (Lewis County)	10 Years	10%
White Salmon River (Skamania County)	10 Years	10%
Black Lake (Thurston County)	40 Years (lake elevation)	~2%
Scott Lake (Thurston County)	40 Years (lake elevation)	~2%
Deschutes River (Thurston County)	45 Years	~2%
Lake Sammamish (King County)	70 Years (lake elevation)	~1.5%
Newaukum River (Lewis County)	100 Years	1%

Twenty-four deaths; $140 million (est.) in insured losses; 250,000 people lost power. More than 130 landslides occurred between Seattle and Everett, primarily along shorelines. Interstate 90 at Snoqualmie pass closed due to avalanche.

March 1997
Federal Disaster (DR-1172)

Stafford Act disaster assistance provided – $6.5 million. Small Business Administration disaster loans approved – $2.9 million.

Heavy rainfall and low-elevation mountain snowmelt caused flooding in counties of Grays Harbor, Jefferson, King, Kitsap, Lincoln, Mason, Pacific, Pierce, Pend Oreille, and Stevens. The table below shows how frequently flooding of the magnitude observed in this event will occur on selected rivers for which data is available.

Table 35 Disaster #1172, Projected Flood Recurrence Interval This Event, Selected Rivers

River (County)	Flood Recurrence Interval	Chance of Annual Occurrence
Naselle River (Pacific County)	100 Years	1%
Satsop River (Grays Harbor County)	200 Years	0.5%
Wynoochee River (Grays Harbor County)	200 Years	0.5%

May 1998
Federal Disaster (DR-1252)

Stafford Act disaster assistance provided – $3.6 million.

Heavy rainfall caused flooding in Ferry and Stevens Counties. Recurrence intervals for flood levels are not available for this disaster.

October 2003[127]
Federal Disaster (DR-1499)

Stafford Act disaster assistance provided to date –$5.8 million. Small Business Administration disaster loans approved – $2.1 million.

Heavy rainfall caused severe flooding in Chelan, Clallam, Grays Harbor, Island, Jefferson, King, Kitsap, Mason, Okanogan, Pierce, San Juan, Skagit, Snohomish, Thurston, and Whatcom counties. Most severe flooding took place along the Skagit River. Record flood levels were set on the Skagit River at Concrete, Sauk River, and Stehekin River. More than 3,400 people were evacuated. Thirty-three homes were destroyed, 112 homes had major damage, with property damage estimated at $30 million. Numerous federal, state and county roads were damaged by landslides and floodwaters.

Table 36 Disaster #1499, Projected Flood Recurrence Interval This Event, Selected Rivers

River (County)	Flood Recurrence Interval	Chance of Annual Occurrence
Nooksack at Deming (Whatcom County)	25 Years	4%
Skagit near Mount Vernon (Skagit County)	40 Years	~2%
Sauk near Sauk (Skagit County)	100 Years	1%
Stillaguamish at Arlington (Snohomish County)	100 Years	1%
Skokomish near Potlatch (Mason County)	100 – 200 Years	0.5 – 1%
Stehekin at Stehekin (Chelan County)	100 – 200 Years	0.5 – 1%

January 2006

Federal Disaster (DR-1641)
Declared by Governor Gregoire on 12 January 2006, this event was the climax of a month of steady rainfall beginning in mid-December. Initially involving counties in the Puget Sound Basin and Spokane, the declaration eventually was extended to all 39 counties. Flooding, landslides and mudflows seriously impacted state and local transportation infrastructure across the state as well as damaging homes and businesses.

November 2006
Federal Disaster (DR-1671)
A total of 2,388 people applied to FEMA for assistance. Stafford Act disaster assistance provided in excess of $38 million. This storm was one of Washington's worst, making it onto the list of *Washington 2006 Top 10 Weather and Climate Events*. [128]

A powerful series of moist subtropical rainstorms battered much of the state from 2-11 November 2006. The Governor proclaimed an initial emergency on 6 November and on 9 November expanded her Proclamation to cover 24 of the state's 39 counties. A number of streams reached record flood levels including the Cowlitz River at Randle; the Snoqualmie River at Carnation; and the Carbon River near Fairfax. Mt. Rainier National Park was severely impacted with damage totals exceeding $30 million to park infrastructure. During the period from November 2 to 7, 24.1 inches of rain fell at the Paradise visitor center, resulting in unprecedented destruction to roads, bridges, campgrounds, trails and other Park facilities.

Washington November 2006 Precipitation Totals[129]

Table 37 City	Nov. 2006	Nov. Normal	Nov. Record	Monthly Record	Graphs & Data
Bellingham	8.10"	5.44"	11.60" (1990)	11.60" (11/1990)	1 Data
Chelan/Lakeside**	2.94"	1.61"	6.20" (1983)	6.20" (11/1983)	1 Data
Forks**	29.28"	17.72"	32.52" (1983)	41.70" (01/1953)	1 Data
Hoquiam*	21.38"	10.30"	18.03 (1990)	19.64" (12/1996)	1 Data
Olympia	19.68"	8.13"	15.51" (1962)	19.84" (01/1953)	1 Data
Quillayute*	30.76"	14.82"	29.14" (1983)	29.14" (11/1983)	1 2 Data
Quinault	51.91"	N/A	N/A	N/A	1 Data
Seattle	15.63"	5.90"	11.62" (1998)	12.92 (01/1953)	1 2 Data
Spokane	4.38"	2.24"	5.85" (1897)	5.85" (11/1897)	1 2 Data
Stampede Pass*	28.03"	12.84"	25.43" (1958)	29.06" (12/1953)	1 Data

Yakima	1.14"	1.05"	2.83" (1973)	5.59" (12/1996)	1 2 Data
Vancouver	13.31"	6.29"	12.92" (1942)	15.04" (12/1933)	1 Data
Denotes new record November rain total * Includes estimated totals for missing data			Denotes new record monthly rain total ** Missing Data		

December 2006
Federal Disaster (DR-1682)

Stafford Act disaster assistance provided in excess of $37 million.

A series of severe winter storms during the time period 14-15 December 2006 caused flooding, landslides and mudslides for 19 Washington counties. High winds reached speeds of 113 mph in the cascades. Saturated soils brought down trees and power lines. A total of 15 fatalities were reported; one woman became trapped in her basement as water rushed into the room and jammed the door shut, 8 were due to carbon monoxide poisoning from generators. The President issued a major disaster declaration as a result of those storms. Under this declaration, the Public Assistance (PA) program of the Federal Emergency Management Agency (FEMA) was made available to entities in Chelan, Clallam, Clark, Grant, Grays Harbor, Island, King, Klickitat, Lewis, Mason, Pacific, Pend Oreille, Pierce, San Juan, Skagit, Skamania, Snohomish, Thurston, and Wahkiakum counties. Recurrence intervals for flood levels are not available for this disaster. Additional information on this disaster is available at: http://www.fema.gov/news/event.fema?published=1&id=7565

December 2007[130]
Federal Disaster (DR-1734)

During the time period December 1-3, 2007, three storms moved over the Pacific Northwest. December 1st marked the first in the series, producing heavy snow in the mountains and low-land snow throughout western Washington. Snow fall levels ranged from a trace to 1” in Seattle, to many areas away from Puget Sound receiving over 4". On December 2nd, the snow changed over to rain as temperatures increased, accompanied by strong winds. As a low pressure system moved over the Olympic Peninsula, wind gusts of over 80 mph were observed along much of the coast (Hoquiam 81, Destruction Island 93, Tatoosh Island 86) and 40 to 50+ mph inland (Olympia 44, Seattle 48, Bellingham 53).

The most significant of the three storms arrived December 3rd, with near record high temperatures (59°F for Seattle) and moist tropical air which led to record rainfall and flooding around western Washington. Reports indicate that 6-hour and 24-hour precipitation amounts were at or near 100-year rain frequency levels. For Sea-Tac Airport, December 3, 2007 became the 2nd wettest day on record with 3.77" (first is 4.93" recorded on October 20, 2003) and the wettest day on record for Bremerton which received 7.50" of rain, breaking the old record of 5.62" set December 10, 1921.

Several sites reached all time record high river flows and set all-time record high flood stage levels, including the Chehalis, which reached nearly 75 ft (10 feet over flood stage), breaking the previous record set in the floods of February 1996. The flooding of the Chehalis River led to widespread flooding throughout western Lewis County, including a stretch of I-5, forcing 20 miles of the interstate to be closed for 4 days. The Coast Guard rescued more than 300 people from the flood areas, and the flooding and mudslides resulted in at least 5 deaths.

A major disaster declaration was issued for 10 counties for Individual Assistance and 12 counties for Public Assistance, comprised of Clallam, Grays Harbor, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Skagit, Snohomish, Thurston, and Wahkiakum counties. Individuals Assistance (IA), SBA low-interest disaster loans, and Public Assistance programs were made available to those jurisdictions impacted

As of March 2008, the breakdown of losses were as follows: 134F[131]

Table 38 County	Housing Assistance (HA)	Other Needs Assistance (ONA)	Small Business Administration (SBA)	Public Assistance (PA)
Clallam	$219,359	$11,623	$251,400	$277,978
Grays Harbor	$1,556,046	$234,918	$3,867,600	$2,326,407
Jefferson	N/A	N/A	N/A	$201,216
King	$1,370,211	$160,353	$1,594,700	$1,845,386
Kitsap	$1,401,024	$59,419	$1,255,500	$1,195,046
Lewis	$9,583,635	$2,266,483	$19,615,500	$8,034,990
Mason	$1,202,781	$58,506	$1,984,700	$1,997,304
Pacific	$475,217	$49,697	$1,340,100	$231,576
Skagit	N/A	N/A	N/A	$21,050
Snohomish	$494,205	$37,233	$724,700	$1,398,783
Thurston	$726,581	$4,180	$823,400	$1,117,943
Wahkiakum	$128,659	$28,531	$85,800	$160,561
Statewide (PA)	N/A	N/A	N/A	$2,104,756
TOTAL	$17,157,718	$2,910,943	$31,543,400	$20,912,996
Legend: **HA** = Housing Assistance**; ONA** = Other Needs Assistance; **SBA** = Small Business Administration Disaster loans; **PA** = Public Assistance for state and local governments, tribes and non-profits (the 75% federal share of completed Project Worksheets); **N/A** = These counties were not designated for Individual Assistance. Additional information on this event is available at: http://www.fema.gov/news/event.fema?published=1&id=9126 and http://www.climate.washington.edu/events/dec2007floods/				

Federal Disaster (DR-1817)[132].

Stafford Act disaster assistance provided approximately $10 million.

A strong, warm, and very wet Pacific weather system brought copious amounts of rainfall to Washington during the period 6-8 January, 2009, with subsequent major flooding extending through January 11, 2009, as well as minor flooding that continued through most of January. The storm involved a strong westerly flow aloft with embedded sub-tropical moisture, known as an *atmospheric river* of moisture. Snow levels rose from low levels to between 6,000 and 8,000 feet, with strong westerly winds enhancing precipitation amounts in the mountains. Antecedent conditions from a mid-December through early January region-wide cold snap and associated heavy snow helped set the stage for the flooding. This event also produced avalanches in the mountains, and caused more than an estimated 1,500 land/mudslides across the state, and resulted in structural damage to buildings from added snow load, compounded by heavy rains.

All counties of Western Washington lowlands received 3-8 inches of rain, while east of the Cascades, amounts ranged from 2 to 7.5 inches. On January 7, 2009, Olympia set a daily record with 4.82 inches. The National Weather Service issued flood warnings for 49 flood warning points across the state. Some daily rainfall records were broken (but not all-time) on January 7th at airports: Sea-Tac saw 2.29 inches that broke 1.33 inches on January 7th in 1996, Olympia saw 4.82 inches breaking 1.95 set on January 7, 2002, and Quillayute saw 2.88 inches breaking 2.39 set on January 7, 1983 (from NWS).

Emergency Alert System was activated by NWS Seattle and Portland as 22 Western Washington rivers exceeded *major* flood category. Two rivers, the Naselle in Pacific County and the Snoqualmie reached all-time record crests. Six rivers had near-record crests, while Mud Mountain Dam and How Hanson Dam had record levels of inflows. The State's primary north-south rail line was also closed and ice jam flooding was also a problem. Interstate-5 was closed from milepost 68 to 89 for 43 hours due to water over the roadway around Chehalis. The economic impact of this closure is estimated at $12 million per day. Public Assistance was provided to 22 counties, while Individual Assistance was provided to 15 counties. 3,465 homeowners and renters applied for federal disaster assistance.

January 2011
Federal Disaster (DR-1963)

The weeks leading up to the flood event featured a number of weather systems that left much of western Washington with saturated soils, healthy snow packs, and rivers that were at high levels.
The series of Pacific weather systems brought large amounts of precipitation to Washington State during January 11-21, 2011, causing flooding, landslides, and mudslides. Widespread flooding was experienced across the Pacific Northwest that was initiated by warm, heavy precipitation and strong winds that produced rainfall and snowmelt. Flood damage resulted in numerous road closures, home evacuations, and the inundation of low-lying lands. This event included King, Kittitas, Klickitat, Lewis, Skagit, Skamania, and Wahkiakum counties. Flooding in the Spokane River Basin was estimated at $255,000 dollars. The Preliminary Data Assessment estimated $8.6 million in total public assistance needed.[133]

January 2012
Federal Disaster (DR- 4056)

A severe winter storm pummeled the Pacific Northwest in late January 2012, icing roads, downing power lines, and prompting avalanche warnings. The period of January 14-19 featured some heavy snowfall and significant freezing rain in the lowlands of western Washington. Precipitation continued on January 19, and much of it fell as freezing rain or snow. The series of Pacific weather systems brought severe winter storms, flooding, landslides, and mudslides to Western Washington State. This snow and ice storm was one of the highest impact weather events for western Washington in a few years. However, it should be recognized that these impacts were minimized by timely warnings from NWS and relatively effective and rapid response by transportation departments and utilities.[134] On January 20, more than 250,000 customers were without electricity.[135] The Preliminary Data Assessment estimated $32 million in total public assistance needed.

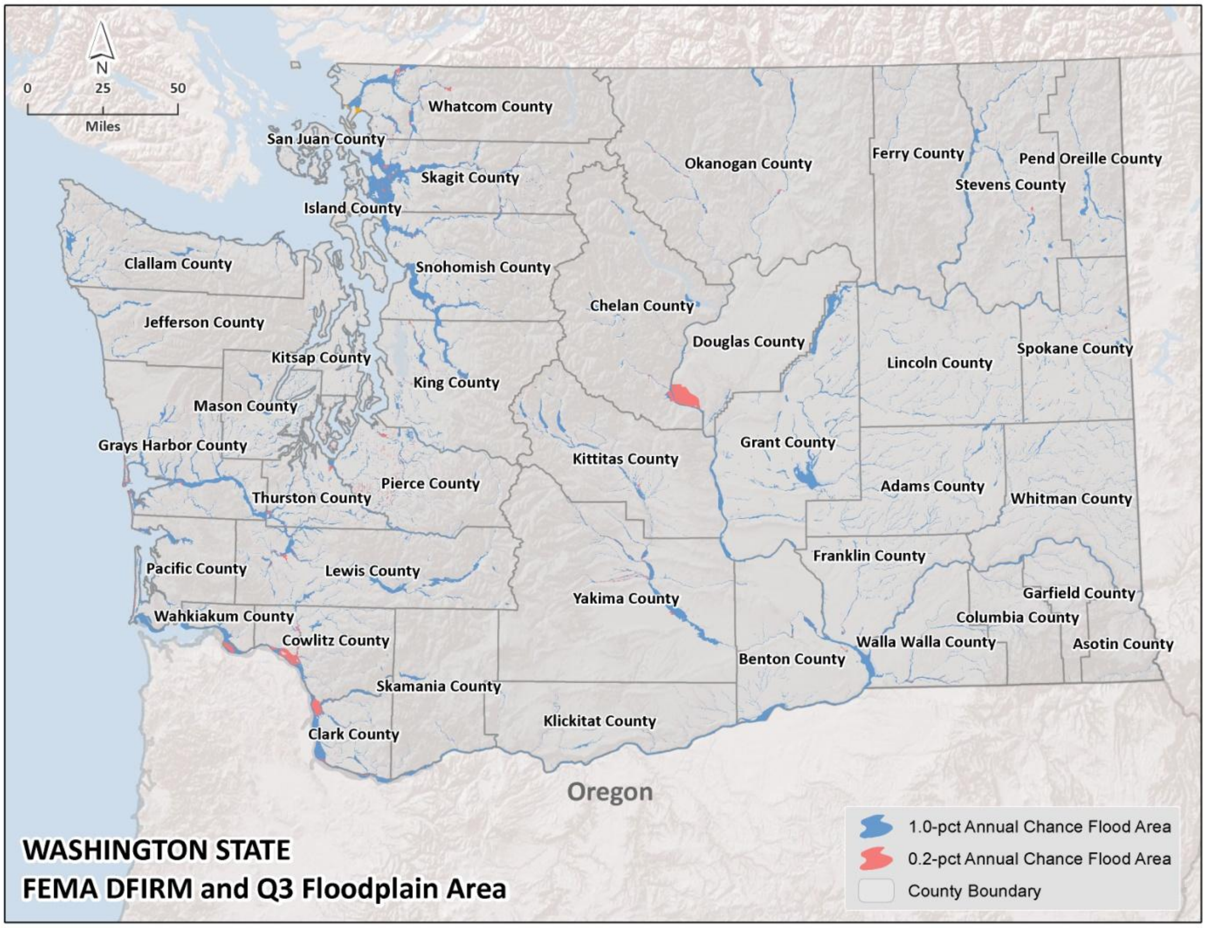
July 2012
Federal Disaster (DR-4083)

On July 20, 2012, a severe thunderstorm hit the region, resulting in flash flooding and significant damage to residential and commercial property. Strong winds of up to 90 miles-per-hour knocked out power and phone service and a damaged storm sewer system prevented local access to clean water for several days. The storm significantly impacted timber, resulting in a $1 million loss for the Washington State Department of Natural Resources and a $2 million loss for the Colville Tribe. One person was also killed in Ferry County as a result of the storm in the Colville National Forest during the thunderstorm and high-intensity winds).[136] In Nespelem and Spring Canyon on Lake Roosevelt , wind gusts peaked at 66 mph and were reported in excess of 50 miles-per-hour. More than 200 trees were knocked down at Daroga State Park in Wenatchee and 80 to 100 mph winds on Daroga Park's island.[137]

Probability of Flooding

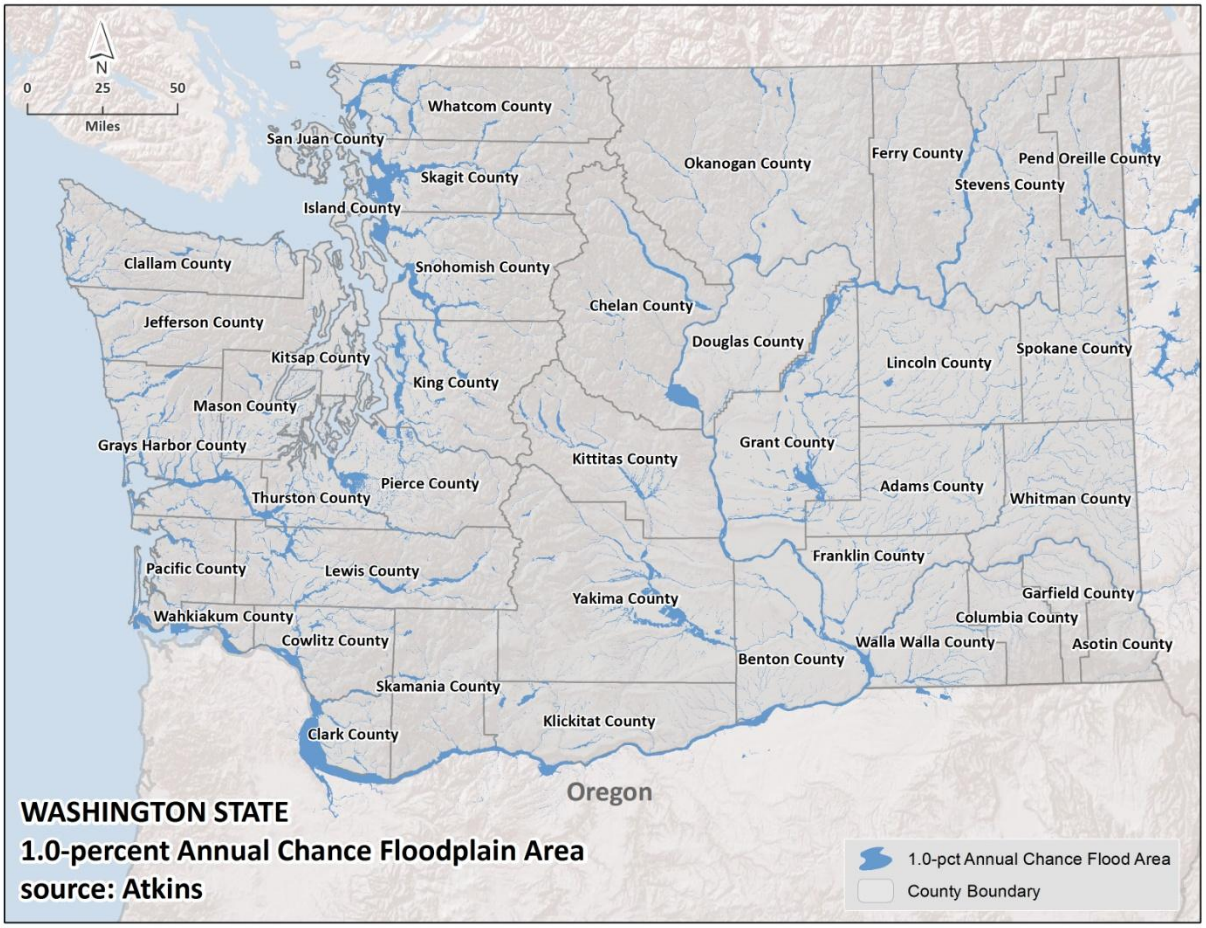
As previously noted, every county in the state has had a Disaster Declaration due to flood. Based on historical records, damaging flood events in Washington State's most flood prone counties will occur every two to eleven years. FEMA regulatory maps are often used to depict these areas, though not all areas in the state are mapped. Where maps are available, the 1.0-percent annual chance and 0.2-percent annual floodplain areas are shown below in Figure 5. It should also be noted that some V zone areas are present in Island, Skagit, Thurston, and Whatcom Counties.

Figure 53 FEMA Regulatory Floodplain Area



For this project, the 1.0-percent annual chance flood was also modeled for this project by Atkins, the contractor responsible for the plan update. Shown in Figure 6 below, these areas indicate a 1.0-percent chance of flooding in any given year based on modeling. However, it should be noted that these areas are not regulatory floodplains.

Figure 54 Modeled 1.0-percent Annual Chance Floodplain



Although floods can happen at any time during the year, there are typical seasonal patterns for flooding in Washington State, based on the variety of natural processes that cause floods:

- Heavy rainfall on wet or frozen ground, before a snow pack has accumulated, typically cause fall and early winter floods.
- Rainfall combined with melting of the low-elevation snow pack typically cause winter and early spring floods. Of particular concern is the phenomenon known as the Pineapple Express, a warm and wet flow of subtropical air originating near Hawaii which can produce multi-day storms with copious rain and very high freezing levels.
- Late spring floods in Eastern Washington result primarily from melting of the snow pack.
- Thunderstorms typically cause flash floods during the summer in Eastern Washington; on rare occasions, thunderstorms embedded in winter-like rainstorms cause flash floods in Western Washington.

Development in or near floodplains increases the likelihood of flood damage in two ways. First, new developments on or adjacent to a flood plain add structures and people in flood areas. Secondly, new construction alters surface water flows by diverting water to new courses or increases the amount of water that runs off impervious pavement and roof surfaces. This second effect diverts waters to places previously safe from flooding.

Hazus-MH Flood Methodology and Results

Hazus-MH 2.1 was used to determine losses with an externally created floodplain. In order to generate this floodplain, Atkins has created an automated tool to run large areas of floodplain analysis using industry accepted techniques. The output generated is consistent with national floodplain standards and is generally of a better quality than what is generated with Hazus' hydrologic and hydraulic (H&H) models.

Flood discharges are derived from published flood gage information and processed through industry-standard statistical analyses to determine values for each return period (i.e., - the 1.0-percent annual chance flood or 0.2-percent annual chance flood). Where available, data indicating special conditions, such as flow regulation, are used to refine the analyses. Flow rates at each modeled cross-section are then extrapolated and interpolated using drainage area as the primary variable. The standard error of prediction is computed at each gage and can be estimated at any other point. The floodplain data was developed using nationally available data sets. The terrain data used for the analysis was the United State Geological Survey 10-meter DEM.

Hydrologic and hydraulic modeling techniques employed with this analysis significantly exceed the minimum standards set by the United States Federal Emergency Management Agency (FEMA) for approximate regulatory flood maps, and include creation of model cross-sections approximately every 300 feet along stream centerlines. A full 1-D steady flow model is developed using this data, and run for specified return periods. For each stream segment, a separate 1-D model is created. The modeling assumes non-coincident peaks as a default, in accordance with FEMA guidelines.

The modeling analysis was run for the 1.0-percent annual chance flood. Depth grids were created using the water surface elevations from the modeling and the USGS 10-meter DEM. These depth grids were imported into Hazus to model the flood losses.

Floodplain data was created at the HUC8 watershed level, which enabled the depth grids to be brought into Hazus with study regions based on HUC8 extents. There are 72 HUC8 watersheds that intersect the State of Washington, and in order to ensure full coverage of the flood data, all but one HUC was included in the analysis. The San Juan Islands watershed (comprised of several islands in the Pacific Ocean) was not included in the Atkins Flood data since there is not enough data to create an automated hydrologic and hydraulic model with the same level of quality as the contiguous portion of the state.[4] Although several return periods could be generated, only the 1.0-percent annual chance return period was used for the Washington State Hazard Mitigation Plan analysis. This was primarily due to time constraints though additional return periods may be explored in future updates of this plan.

FEMA Region 10 supplied the Hazus inventory data that was used for the Hazus General Building Stock (GBS) analysis. The Region 10 data, which has been recently updated, replaced the default Hazus inventory data that is largely based on the 2000 Census.

[4] Riverine level losses were not available for San Juan County. However, as discussed in detail below, coastal flood losses were available.

As previously noted, these floodplains may not be used for regulatory flood determinations in the United States, unless a formal Best Available Data Letter (BADL) has been obtained for the area of interest.

In addition to floodplain generation and Hazus-MH analysis, inflation was accounted for in order to estimate approximate 2012 value of losses. The Consumer Price Index (CPI) is a common measure of inflation and was used herein. State CPI's are not determined but national and metropolitan-level (with populations over 1.5 million) values are calculated. According to the Washington Office of Financial Management, the Seattle Metropolitan Statistical Area CPI (including Seattle, Tacoma, and Bremerton) is the closest representative to a state CPI. It should also be noted that the CPI at the metropolitan level is subject to measurement errors and can be more volatile given the smaller area. According to the Seattle CPI, the cumulative rate of inflation between 2000 and 2012 was calculated to be 29.9 percent. In other words, $1.00 in 2000 would be $1.29 in 2012.[138] The national rate of inflation during this time was 33.3 percent. The results are shown in Table 2 and Figure 7 below.

Hazus-MH 2.1 Flood Results

Table 39. Hazus-MH 2.1 General Building Stock (GBS) Total Losses for 1.0-percent Annual Chance Riverine Flood

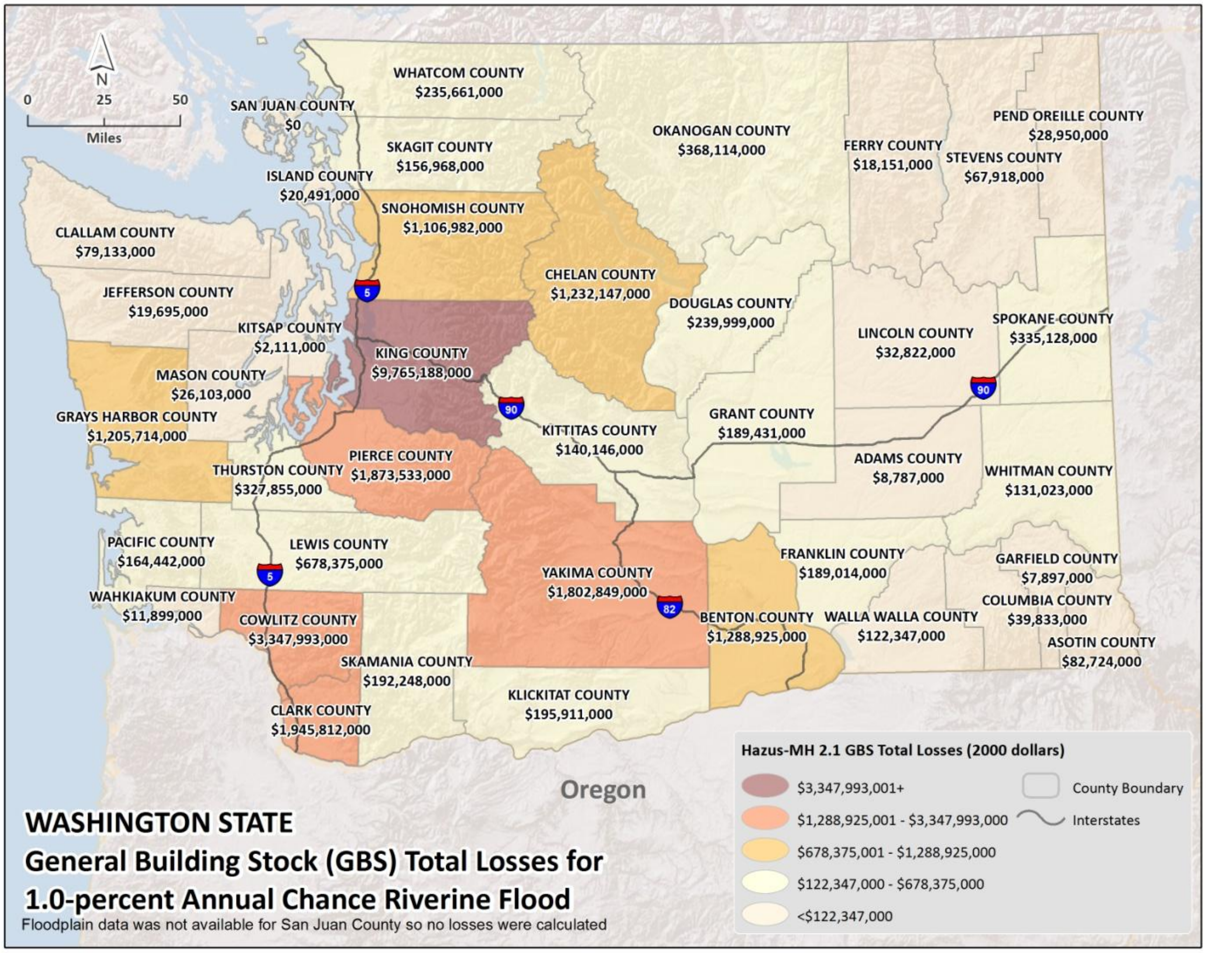
	GBS Total Losses*	GBS Building Losses	GBS Contents Losses	GBS Inventory Losses	GBS Total Losses Inflated to 2012 dollars
Adams	$8,787,000	$3,553,000	$4,906,000	$304,000	$11,413,538
Asotin	$82,724,000	$36,484,000	$44,469,000	$1,292,000	$107,451,182
Benton	$1,288,925,000	$575,302,000	$693,503,000	$11,013,000	$1,674,199,931
Chelan	$1,232,147,000	$586,471,000	$616,600,000	$23,612,000	$1,600,450,315
Clallam	$79,133,000	$39,367,000	$38,652,000	$941,000	$102,786,790
Clark	$1,945,812,000	$979,262,000	$906,534,000	$54,834,000	$2,527,438,226
Columbia	$39,833,000	$19,881,000	$19,401,000	$445,000	$51,739,555
Cowlitz	$3,347,993,000	$1,296,265,000	$1,626,579,000	$356,100,000	$4,348,747,716
Douglas	$239,999,000	$134,343,000	$101,650,000	$3,251,000	$311,737,540
Ferry	$18,151,000	$10,087,000	$7,958,000	$91,000	$23,576,549
Franklin	$189,014,000	$89,818,000	$94,709,000	$3,934,000	$245,512,521
Garfield	$7,897,000	$3,885,000	$3,929,000	$64,000	$10,257,507
Grant	$189,431,000	$103,564,000	$83,068,000	$2,128,000	$246,054,167
Grays Harbor	$1,205,714,000	$457,984,000	$578,992,000	$158,010,000	$1,566,116,179
Island	$20,491,000	$12,190,000	$8,249,000	$30,000	$26,616,002
Jefferson	$19,695,000	$10,189,000	$9,145,000	$246,000	$25,582,068
King	$9,765,188,000	$3,892,642,000	$5,524,413,000	$301,348,000	$12,684,118,219
Kitsap	$2,111,000	$1,139,000	$961,000	$11,000	$2,742,003
Kittitas	$140,146,000	$68,107,000	$69,379,000	$2,085,000	$182,037,297
Klickitat	$195,911,000	$111,391,000	$81,342,000	$2,792,000	$254,471,116
Lewis	$678,375,000	$273,524,000	$384,014,000	$17,449,000	$881,149,313
Lincoln	$32,822,000	$13,883,000	$18,272,000	$463,000	$42,632,884
Mason	$26,103,000	$13,753,000	$12,047,000	$268,000	$33,905,496

Table 39. Hazus-MH 2.1 General Building Stock (GBS) Total Losses for 1.0-percent Annual Chance Riverine Flood

	GBS Total Losses*	GBS Building Losses	GBS Contents Losses	GBS Inventory Losses	GBS Total Losses Inflated to 2012 dollars
Okanogan	$368,114,000	$186,032,000	$175,684,000	$5,342,000	$478,147,630
Pacific	$164,442,000	$70,068,000	$90,120,000	$2,637,000	$213,595,659
Pend Oreille	$28,950,000	$17,034,000	$11,732,000	$159,000	$37,603,497
Pierce	$1,873,533,000	$810,092,000	$1,001,038,000	$55,027,000	$2,433,554,178
San Juan**	--	--	--	--	--
Skagit	$156,968,000	$86,625,000	$68,727,000	$1,331,000	$203,887,592
Skamania	$192,248,000	$111,727,000	$78,733,000	$897,000	$249,713,202
Snohomish	$1,106,982,000	$508,734,000	$575,668,000	$19,691,000	$1,437,872,016
Spokane	$335,128,000	$154,680,000	$175,142,000	$4,042,000	$435,301,724
Stevens	$67,918,000	$34,396,000	$32,033,000	$1,084,000	$88,219,494
Thurston	$327,855,000	$165,139,000	$158,197,000	$3,438,000	$425,854,738
Wahkiakum	$11,899,000	$5,399,000	$6,190,000	$125,000	$15,455,752
Walla Walla	$122,347,000	$46,211,000	$72,978,000	$2,168,000	$158,917,966
Whatcom	$235,661,000	$111,648,000	$120,026,000	$3,298,000	$306,102,861
Whitman	$131,023,000	$51,832,000	$77,057,000	$1,511,000	$170,187,325
Yakima	$1,802,849,000	$579,565,000	$898,129,000	$303,246,000	$2,341,741,894
Washington State	$27,725,131,000	$11,695,290,000	$14,470,226,000	$1,344,707,000	$35,956,891,641

* Total loss includes building, contents, inventory, relocation, income, rental income, wage, direct output, and employments losses determined by the scenario as a result of riverine flooding.
**The necessary National Hydrography Data (NHD) data required for automated modeling does not exist for this county so a riverine floodplain could not be generated.
Source: Hazus-MH 2.1, Level 2 (enhanced) hazard run

Figure 55 Hazus-MH 2.1 General Building Stock Loss Estimates for the 1.0-percent Annual Chance Riverine Flood



In order to present a complete picture of risk and losses due to flooding, coastal losses were also garnered. Coastal losses were derived from the results of the nationwide Hazus Average Annualized Loss (AAL) Usability Analysis which concluded in 2010. The study used Hazus-MH MR 4 with a 30-meter digital elevation model (DEM) to complete a Level 1 (basic) flood boundary. Coastal Still Water Elevations were used from the available regulatory Flood Insurance Study reports for counties where coastal flood data was created. Conclusions of the study noted that the AAL Usability Analysis provided reasonable results though lack of detail in the DEM was attributed to larger than expected losses in some areas. For the purpose of showing coastal flood losses in this plan, the coastal AAL results were added to the riverine flood results (as presented above). Table 3 and Figure 8 below shows the combined riverine and coastal flood losses due to the 1.0-percent annual chance flood.

Table 40. Hazus-MH 2.1 General Building Stock (GBS) Total Losses for 1.0-percent Annual Chance Riverine and Coastal Flood

	GBS Total Losses*	GBS Building Losses	GBS Contents Losses	GBS Inventory Losses	GBS Total Losses Inflated to 2012 dollars
Adams	$8,787,000	$3,553,000	$4,906,000	$304,000	$11,413,538
Asotin	$82,724,000	$36,484,000	$44,469,000	$1,292,000	$107,451,182

Table 40. Hazus-MH 2.1 General Building Stock (GBS) Total Losses for 1.0-percent Annual Chance Riverine and Coastal Flood

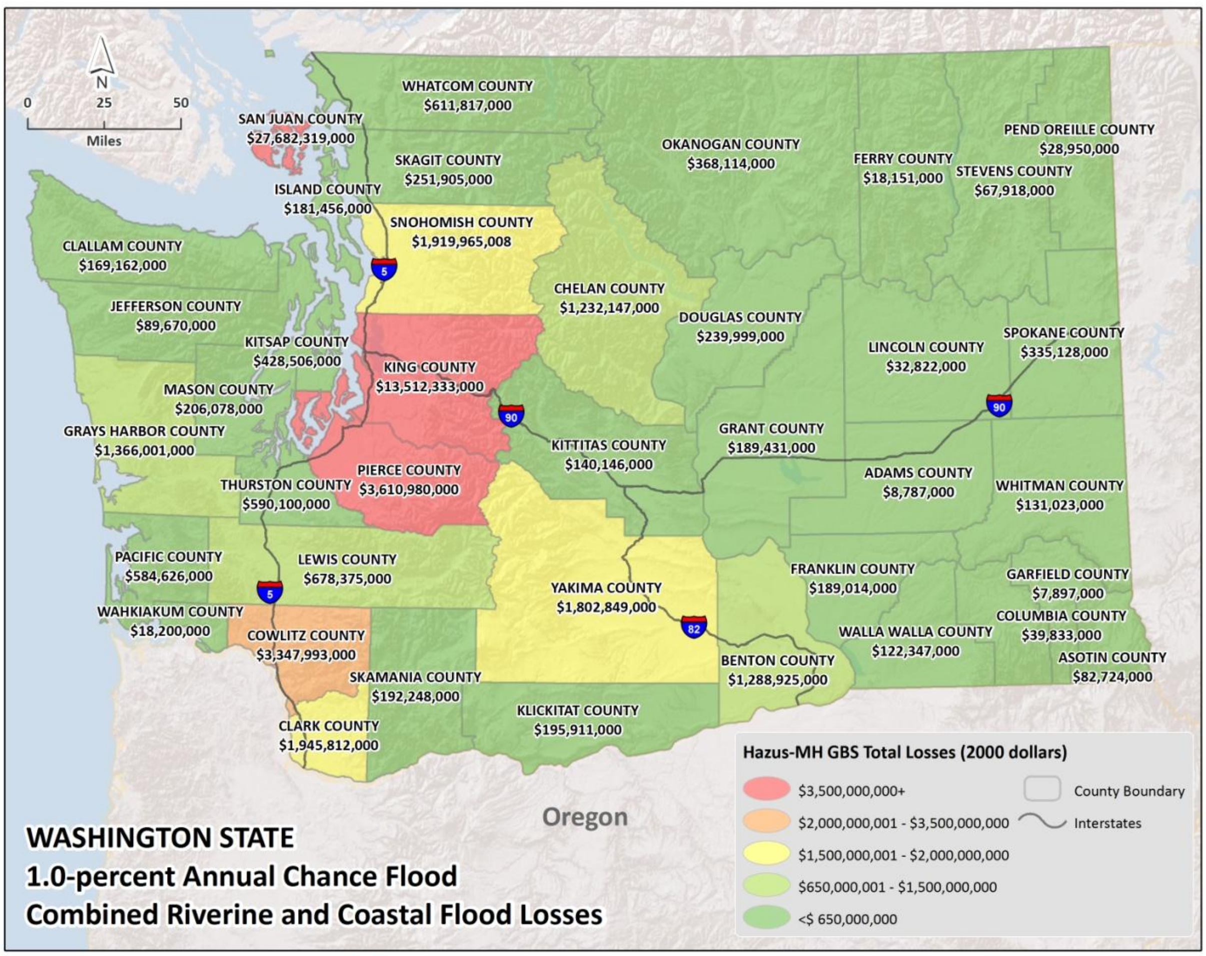
	GBS Total Losses*	GBS Building Losses	GBS Contents Losses	GBS Inventory Losses	GBS Total Losses Inflated to 2012 dollars
Benton	$1,288,925,000	$575,302,000	$693,503,000	$11,013,000	$1,674,199,931
Chelan	$1,232,147,000	$586,471,000	$616,600,000	$23,612,000	$1,600,450,315
Clallam	$169,162,000	$77,588,000	$86,519,000	$941,000	$219,726,523
Clark	$1,945,812,000	$979,262,000	$906,534,000	$54,834,000	$2,527,438,226
Columbia	$39,833,000	$19,881,000	$19,401,000	$445,000	$51,739,555
Cowlitz	$3,347,993,000	$1,296,265,000	$1,626,579,000	$356,100,000	$4,348,747,716
Douglas	$239,999,000	$134,343,000	$101,650,000	$3,251,000	$311,737,540
Ferry	$18,151,000	$10,087,000	$7,958,000	$91,000	$23,576,549
Franklin	$189,014,000	$89,818,000	$94,709,000	$3,934,000	$245,512,521
Garfield	$7,897,000	$3,885,000	$3,929,000	$64,000	$10,257,507
Grant	$189,431,000	$103,564,000	$83,068,000	$2,128,000	$246,054,167
Grays Harbor	$1,366,001,000	$538,209,000	$654,318,000	$158,010,000	$1,774,314,859
Island	$181,456,000	$102,191,000	$77,998,000	$30,000	$235,695,345
Jefferson	$89,670,000	$42,462,000	$44,672,000	$246,000	$116,473,424
King	$13,512,333,000	$5,209,259,000	$7,763,768,000	$301,348,000	$17,551,329,189
Kitsap	$428,506,000	$195,887,000	$226,230,000	$11,000	$556,591,513
Kittitas	$140,146,000	$68,107,000	$69,379,000	$2,085,000	$182,037,297
Klickitat	$195,911,000	$111,391,000	$81,342,000	$2,792,000	$254,471,116
Lewis	$678,375,000	$273,524,000	$384,014,000	$17,449,000	$881,149,313
Lincoln	$32,822,000	$13,883,000	$18,272,000	$463,000	$42,632,884
Mason	$206,078,000	$103,124,000	$99,455,000	$268,000	$267,677,152
Okanogan	$368,114,000	$186,032,000	$175,684,000	$5,342,000	$478,147,630
Pacific	$584,626,000	$243,519,000	$324,617,000	$2,637,000	$759,377,628
Pend Oreille	$28,950,000	$17,034,000	$11,732,000	$159,000	$37,603,497
Pierce	$3,610,980,000	$1,450,117,000	$2,008,640,000	$55,027,000	$4,690,344,641
San Juan**	$27,682,319,000	$11,672,266,000	$14,470,226,000	$0	$35,956,891,641
Skagit	$251,905,000	$133,550,000	$113,451,000	$1,331,000	$327,202,385
Skamania	$192,248,000	$111,727,000	$78,733,000	$897,000	$249,713,202
Snohomish	$1,919,965,008	$850,119,000	$1,025,052,000	$19,691,000	$2,493,865,263
Spokane	$335,128,000	$154,680,000	$175,142,000	$4,042,000	$435,301,724
Stevens	$67,918,000	$34,396,000	$32,033,000	$1,084,000	$88,219,494
Thurston	$590,100,000	$273,291,000	$298,872,000	$3,438,000	$766,487,871
Wahkiakum	$18,200,000	$8,364,000	$9,304,000	$125,000	$23,640,195
Walla Walla	$122,347,000	$46,211,000	$72,978,000	$2,168,000	$158,917,966
Whatcom	$611,817,000	$271,165,000	$323,013,000	$3,298,000	$794,696,339

Table 40. Hazus-MH 2.1 General Building Stock (GBS) Total Losses for 1.0-percent Annual Chance Riverine and Coastal Flood

	GBS Total Losses*	GBS Building Losses	GBS Contents Losses	GBS Inventory Losses	GBS Total Losses Inflated to 2012 dollars
Whitman	$131,023,000	$51,832,000	$77,057,000	$1,511,000	$170,187,325
Yakima	$1,802,849,000	$579,565,000	$898,129,000	$303,246,000	$2,341,741,894
Washington State	$63,909,662,008	$26,658,408,000	$33,803,936,000	$1,344,707,000	$83,013,016,056

* Total loss includes building, contents, inventory, relocation, income, rental income, wage, direct output, and employments losses determined by the scenario as a result of riverine flooding.
** The necessary National Hydrography Data (NHD) data required for automated modeling does not exist for this county so a riverine floodplain could not be generated. Therefore, only Hazus-MH MR4 coastal model flood and associated results were utilized.
Source: Hazus-MH 2.1, Level 2 (enhanced) hazard run

Figure 56 Hazus-MH 2.1 General Building Stock Loss Estimates for the 1.0-percent Annual Chance Riverine and Coastal Flood Impacts



Jurisdictions Most Vulnerable to Flooding

The factors used to determine which counties are most vulnerable to future flooding are:

- Frequency of flooding that causes major damage, based on the number of Presidential Disaster Declarations since 1956 as an indicator of how often serious, damaging flood events occur (top 20 counties). An approximated reoccurrence interval was also estimated using this data.
- Percentage of the County in Floodplain (land area only minus water bodies) (2 percent of more of the area of the county) – a measure of the size of the area within a county at-risk to flooding.
- Counties with the top 20 highest total General Building Stock Losses in Hazus-MH 2.1 from the 1.0-percent annual chance flood scenario.
- Number of Flood Insurance Policies Currently in Effect (top 20 counties) – a measure of the built environment in the floodplain.
- Number of Flood Insurance Claims Paid Since 1978 (top 20 counties) – another measure of the built environment in the floodplain.
- Number of Repetitive Flood Loss Properties (measured by county) – a measure of how often serious, damaging flood events occur.
- Number of Severe Repetitive Loss Properties (measured by county) – a measure of how often serious, damaging flood events occur.

Based on these factors, the following counties are at ten with the greatest risk and most vulnerable to flooding:

Table 41 Jurisdictions Most Vulnerable to Flooding

Clark	Pierce
Cowlitz	Skagit
Grays Harbor	Snohomish
King	Thurston
Lewis	Whatcom

Frequency of Major Flood Occurrence

Presidential Disaster Declarations provide a good indicator of major damage caused by a hazard event. There have been 32 Presidential Disaster Declarations for flooding since 1956. Each county has received at least five disaster declarations for flooding since 1956.[139]

The counties in Table 4 below are those that have experienced the most frequent flooding resulting in major damages and a Presidential Disaster Declaration since 1956. The approximated reoccurrence interval using this data is found in the table below for the top twenty counties. Occurrence rates are approximate, and rounded to the nearest year. This information also depicted in Figure 9.

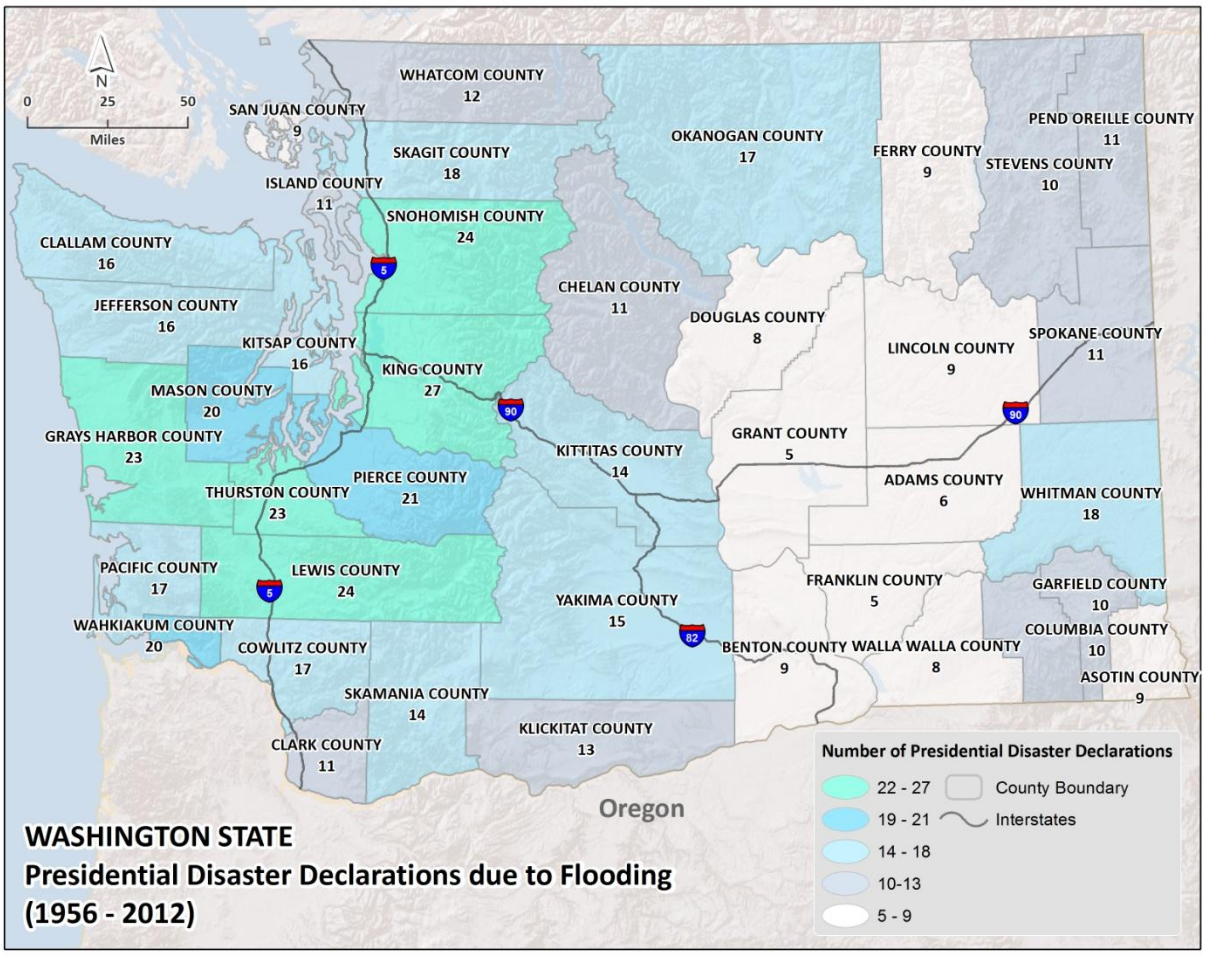
Table 42. Twenty Counties with Highest Number of Presidential Disaster Declarations Due to Flooding and Approximate Interval Between Major Flood Events, 1956 through 2012

County	#	Interval (years)	County	#	Interval (years)
King County	27	2	Cowlitz County	17	3

Table 42. Twenty Counties with Highest Number of Presidential Disaster Declarations Due to Flooding and Approximate Interval Between Major Flood Events, 1956 through 2012

County	#	Interval (years)	County	#	Interval (years)
Lewis County	24	2	Okanogan County	17	3
Snohomish County	24	2	Pacific County	17	3
Grays Harbor County	23	2	Clallam County	16	4
Thurston County	23	2	Jefferson County	16	4
Pierce County	21	3	Kitsap County	16	4
Mason County	20	3	Yakima County	15	4
Wahkiakum County	20	3	Kittitas County	14	4
Skagit County	18	3	Skamania County	14	4
Whitman County	18	3	Klickitat County	13	4

Figure 57 Number of Presidential Disasters due to Flooding per County



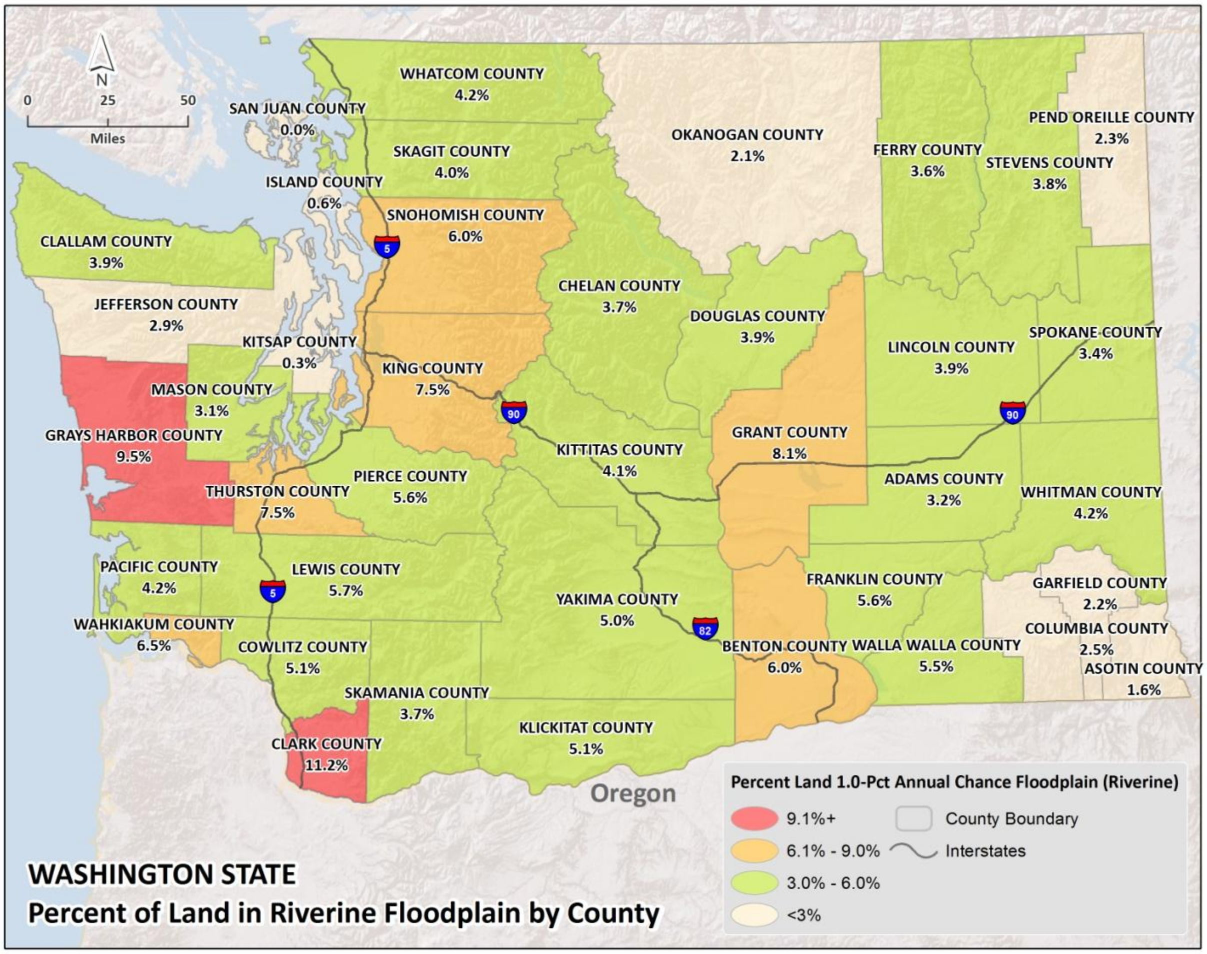
Percentage of County in Riverine Floodplain

The top twenty counties have 1.0-percent annual chance floodplain varying from 11.2 percent to 4.0 percent of their total county area. This information is shown in Table 5 below and also depicted in Figure 10.

Table 43. Twenty Counties with Highest Percentage of County Covered by 1.0-percent Annual Chance Floodplain (top twenty)

County	Total Sq. Mi.	1.0-% ACF (Sq. Mi.)	% in FP	County	Total Sq. Mi.	1.0-% ACF (Sq. Mi.)	% in FP
Clark	655.7	73.3	11.2	Pierce	1,689.9	94.9	5.6
Grays Harbor	1,929.2	182.4	9.5	Walla Walla	1,302.1	72.0	5.5
Grant	2,794.0	227.0	8.1	Cowlitz	1,165.4	59.8	5.1
King	2,188.1	165.2	7.5	Klickitat	1,904.0	96.4	5.1
Thurston	735.5	55.5	7.5	Yakima	4,311.4	217.1	5.0
Wahkiakum	265.4	17.3	6.5	Whatcom	2,162.0	91.4	4.2
Benton	1,761.8	106.2	6.0	Pacific	938.0	39.4	4.2
Snohomish	2,106.9	127.0	6.0	Whitman	2,185.2	91.3	4.2
Lewis	2,434.5	137.8	5.7	Kittitas	2,333.0	96.2	4.1
Franklin	1,267.4	71.4	5.6	Skagit	1,754.8	70.2	4.0

Figure 58 Percentage of County Covered by 1.0-percent Annual Chance Flood.



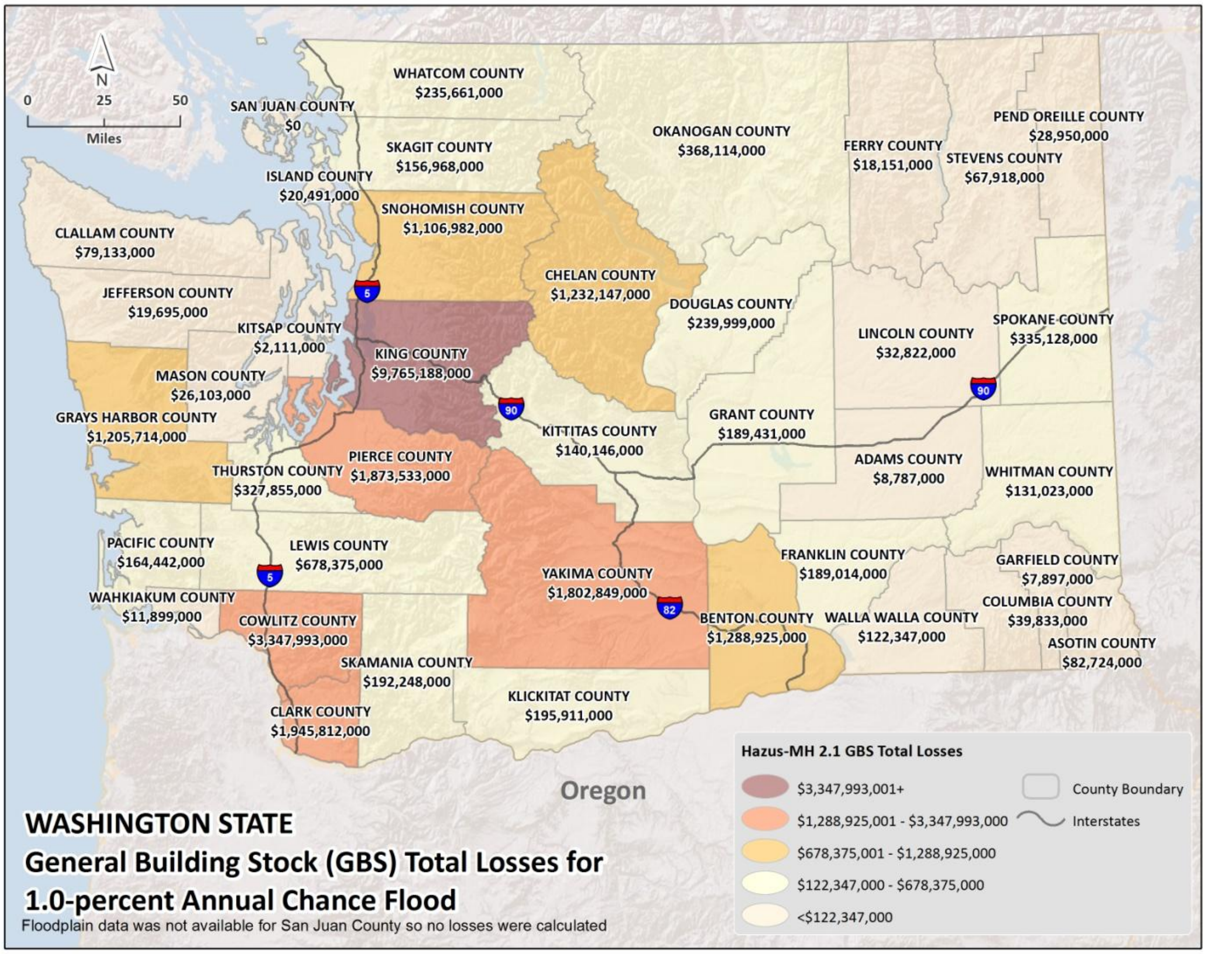
Hazus-MH Losses

The counties with the top twenty highest total general building stock losses from the 1.0-percent annual chance riverine flood are shown in Table 6 and Figure 11 below:

Table 44. Twenty Counties with Highest Hazus-MH 2.1 GBS Loss Estimates

County	GBS Total Losses	County	GBS Total Losses
King	$9,765,188,000	Okanogan	$368,114,000
Cowlitz	$3,347,993,000	Spokane	$335,128,000
Clark	$1,945,812,000	Thurston	$327,855,000
Pierce	$1,873,533,000	Douglas	$239,999,000
Yakima	$1,802,849,000	Whatcom	$235,661,000
Benton	$1,288,925,000	Klickitat	$195,911,000
Chelan	$1,232,147,000	Skamania	$192,248,000
Grays Harbor	$1,205,714,000	Grant	$189,431,000
Snohomish	$1,106,982,000	Franklin	$189,014,000
Lewis	$678,375,000	Pacific	$164,442,000

Figure 59 Hazus-MH 2.1 GBS Losses by County



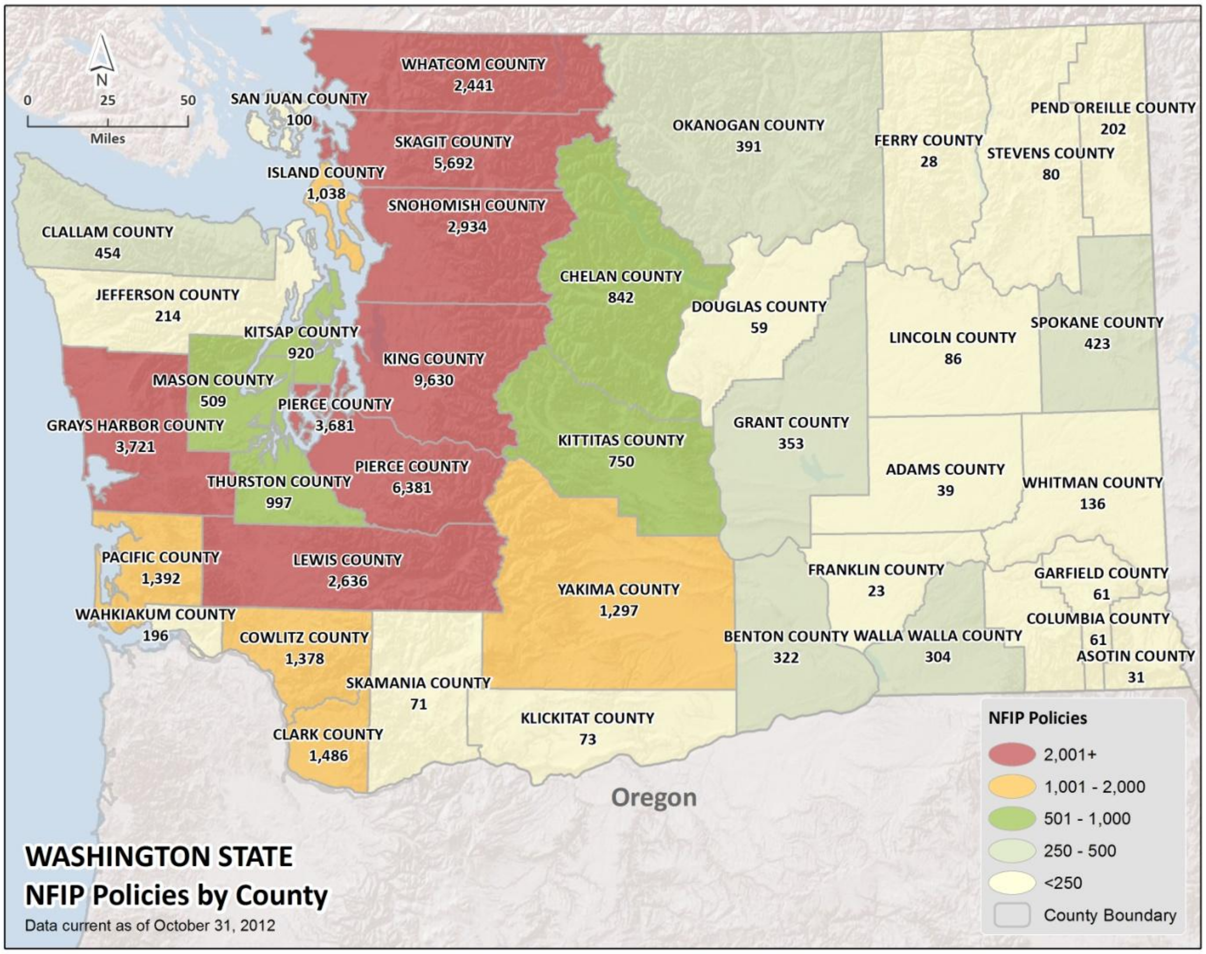
National Flood Insurance Program (NFIP) Policies in Place[140]
Table 7 below shows the twenty counties with the largest number of flood insurance policies currently in force as of October 31, 2012. This number includes their cities, towns, and unincorporated areas. Figure 12 follows which shows policies throughout the state.

Table 45. Twenty Counties with Highest Number of NFIP Policies in Force

County	# Policies	County	# Policies
King	9,630	Yakima	1,297
Skagit	5,692	Island	1,038
Grays Harbor	3,721	Thurston	997
Pierce	3,681	Kitsap	920
Snohomish	2,934	Chelan	842
Lewis	2,636	Kittitas	750
Whatcom	2,441	Mason	509
Clark	1,486	Clallam	454
Pacific	1,392	Spokane	423

Cowlitz	1,378	Okanogan	391

Figure 60 Number of NFIP Policies by County



Flood Insurance Claims[141]

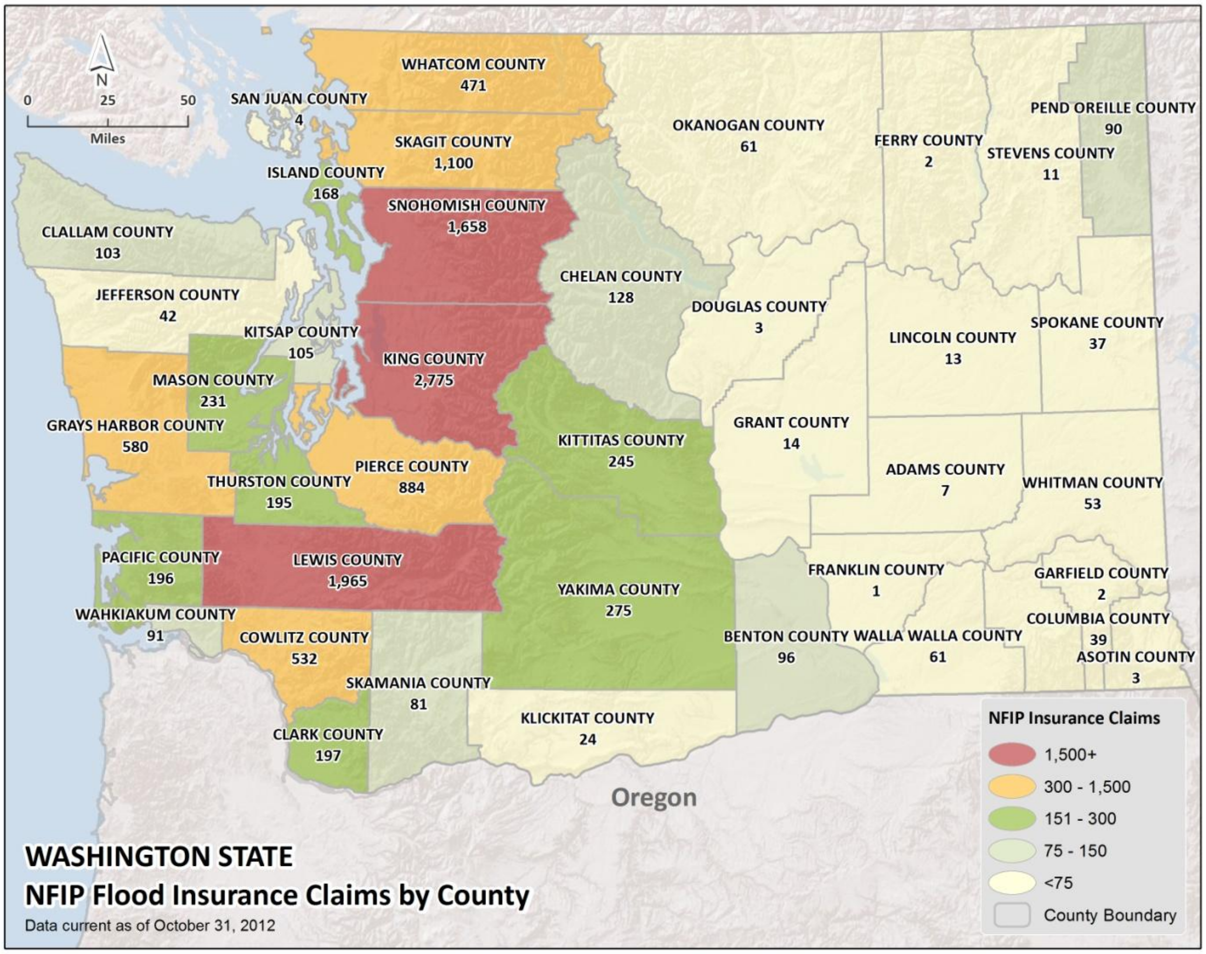
Table 8 below shows the twenty counties with most flood insurance claims. This number includes their cities, towns, and unincorporated areas. Figure 13, following the table, shows the claims throughout the state. A complete list of all claim information filed is available at the end of this section as Appendix A.

Table 46. Twenty Counties with Highest Number of NFIP Claims

County	# Claims	County	# Claims
King	2,775	Kittitas	245
Lewis	1,965	Mason	231
Snohomish	1,658	Clark	197
Skagit	1,100	Pacific	196
Pierce	884	Island	168
Grays Harbor	580	Chelan	128
Cowlitz	532	Kitsap	105
Whatcom	471	Clallam	103
Thurston	295	Benton	96

Yakima	275	Wahkiakum	91

Figure 60 Number of NFIP Claims by County



Lastly, NFIP policies and claims are reported by county in Table 9 below.

Table 47. Flood Insurance Policies and Claims by County* Through October 31, 2012

County	No. of Policies	No. of Claims Filed
King	9,630	2,775
Skagit	5,692	1,100
Grays Harbor	3,721	580
Pierce	3,681	884
Snohomish	2,934	1658
Lewis	2,636	1,965
Whatcom	2,441	471
Clark	1,486	197
Pacific	1,392	196
Cowlitz	1,378	532
Yakima	1,297	275
Island	1,038	168

Table 47. Flood Insurance Policies and Claims by County* Through October 31, 2012

County	No. of Policies	No. of Claims Filed
Thurston	997	195
Kitsap	920	105
Chelan	842	128
Kittitas	750	245
Mason	509	231
Clallam	454	103
Spokane	423	37
Okanogan	391	61
Grant	353	14
Benton	322	96
Walla Walla	304	61
Jefferson	214	42
Pend Oreille	202	90
Wahkiakum	196	91
Whitman	136	53
San Juan	100	4
Lincoln	86	13
Stevens	80	11
Klickitat	73	24
Skamania	71	81
Columbia	61	39
Garfield	61	2
Douglas	59	3
Adams	39	7
Asotin	31	3
Ferry	28	2
Franklin	23	1
TOTALS	45,093	12,647

* County total – includes incorporated cities and towns

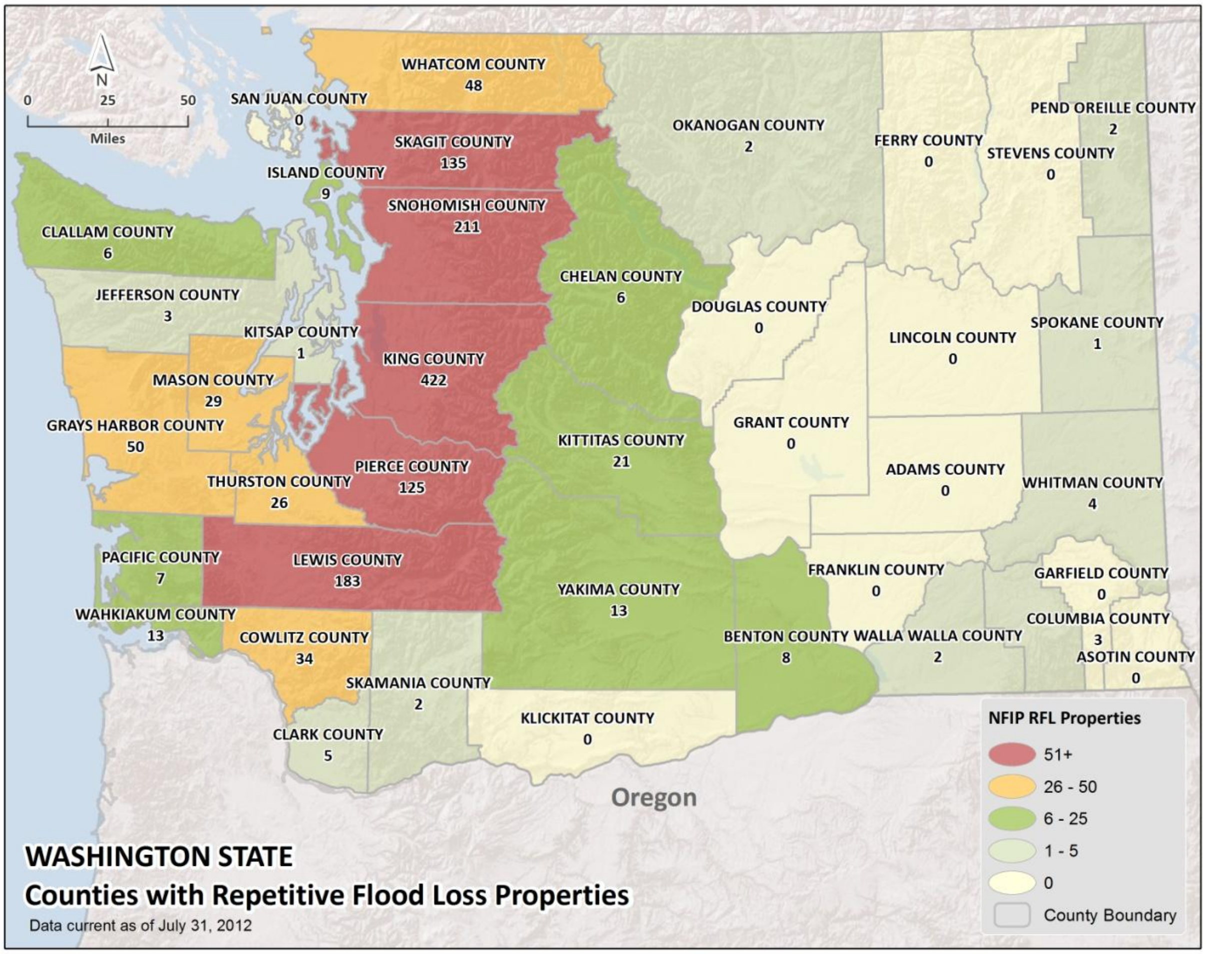
Repetitive Flood Loss (RFL) Properties[142]

Repetitive Flood Loss Properties can also be an indication of flood risk and vulnerabiilty in the are. Counties with RFL properties are listed in Table 10 and shown in the Figure 14 below.

Table 48. Counties with RFL Properties

County	# RFL Properties*	County	# RFL Properties*
King	422	Benton	8
Snohomish	211	Pacific	7
Lewis	183	Chelan	6
Skagit	135	Clallam	6
Pierce	125	Clark	5
Grays Harbor	50	Whitman	4
Whatcom	48	Jefferson	3
Cowlitz	34	Columbia	3
Mason	29	Okanogan	2
Thurston	26	Pend Oreille	2
Kittitas	21	Skamania	2
Wahkiakum	13	Walla Walla	2
Yakima	13	Kitsap	1
Island	9	Spokane	1
* Current as of July 2012			
Note: County totals include properties in the unincorporated areas of the County as well as the properties inside of the limits of the incorporated cities and towns within those Counties.			

Figure 61 Number of NFIP Repetitive Flood Loss Properties by County

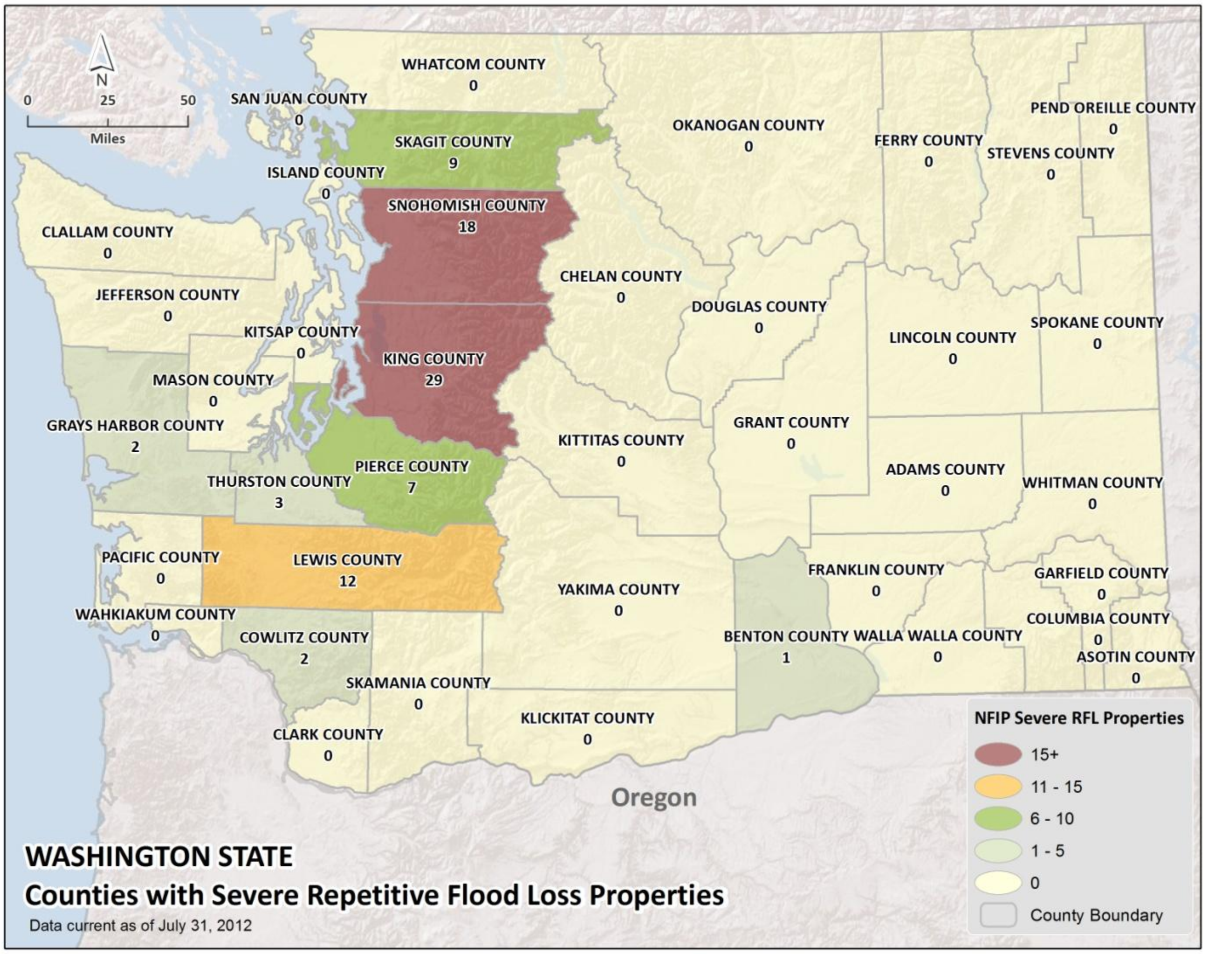


Severe Repetitive Flood Loss Properties[143]
Severe Repetitive Flood Loss Properties can also be an indication of flood risk and vulnerabiilty in the are. Counties with Severe RFL properties are listed in Table 11 and shown in Figure 15 below.

Table 49. Counties with SRL Properties

County	# Severe RFL Properties*
King	29
Snohomish	18
Lewis	12
Skagit	9
Pierce	7
Thurston	3
Cowlitz	2
Grays Harbor	2
Benton	1
Whatcom	1
Total	91
* Current as of July 2012	

Figure 62 Number of NFIP Severe Repetitive Flood Loss Properties by County



Jurisdictions Most Vulnerable to Flooding

Jurisdictions most vulnerable to flooding were determined by scoring each county based on the above factors of frequency of flooding that causes major damage, the percentage of the county in floodplain, the number of flood insurance policies currently in effect, the number of flood insurance claims paid, the number of repetitive flood loss properties, and the number of severe repetitive loss properties. The scoring metric is shown in Table 12 below. The jurisdictional results are in Table 13 and Figure 16 below. A maximum value of 28 points was possible (King County received this score). The ten counties with the highest score are considered most vulnerable to flooding and are highlighted in Table 13 and in the Figure 16. Note that county totals include properties in the unincorporated areas of the County as well as the properties inside of the limits of the incorporated cities and towns within those Counties.

Table 50. Scoring Metric for Determining Most Vulnerable Jurisdictions

Approx. Frequency of Occurrence	% Area in 1-pct Riverine ACF	Hazus-MH 2.1 GBS Losses	# Flood Insurance Policies	# Flood Insurance Claims	# Repetitive Flood Loss Properties	# Severe Repetitive Loss	Score
3 Yrs.	6.5% or More	>$2bil	> 2,000	> 750	> 100	10 or more	4 pts each
4 Yrs.	4.0 – 6.4%	$1-2bil	1,000 – 1,999	300 – 749	50 - 99	7 to 9	3 pts each
5 Yrs.	3.0 – 3.9%	$100mil - 1bill	500 – 999	100 – 299	20 - 49	4 to 6	2 pts each
6+Yrs.	0 – 2.9%	<100mil	250 – 499	1 – 99	1 - 19	1 to 3	1 pt each

Table 51. Jurisdictional Results

COUNTY	Approx. Frequency of Occurrence	% Area in 1-pct Riverine ACF	Hazus-MH 2.1 GBS Losses	# Flood Insurance Policies	# Flood Insurance Claims	# Repetitive Flood Loss Properties	# SRL Properties	Score
Adams County	9	3.2	$8,787,000	39	7	-	0	5
Asotin County	6	1.6	$82,724,000	31	3	-	0	4
Benton County	6	6.0	$1,288,925,000	322	96	8	1	9
Chelan County	5	3.7	$1,232,147,000	842	128	6	0	12
Clallam County	4	3.9	$79,133,000	454	103	6	0	10
Clark County	5	11.2	$1,945,812,000	1,486	197	5	0	16
Columbia County	6	2.5	$39,833,000	61	39	3	0	5
Cowlitz County	3	5.1	$3,347,993,000	1,378	532	34	2	20
Douglas County	7	3.9	$239,999,000	59	3	-	0	6
Ferry County	6	3.6	$18,151,000	28	2	-	0	4
Franklin County	11	5.6	$189,014,000	23	1	-	0	7

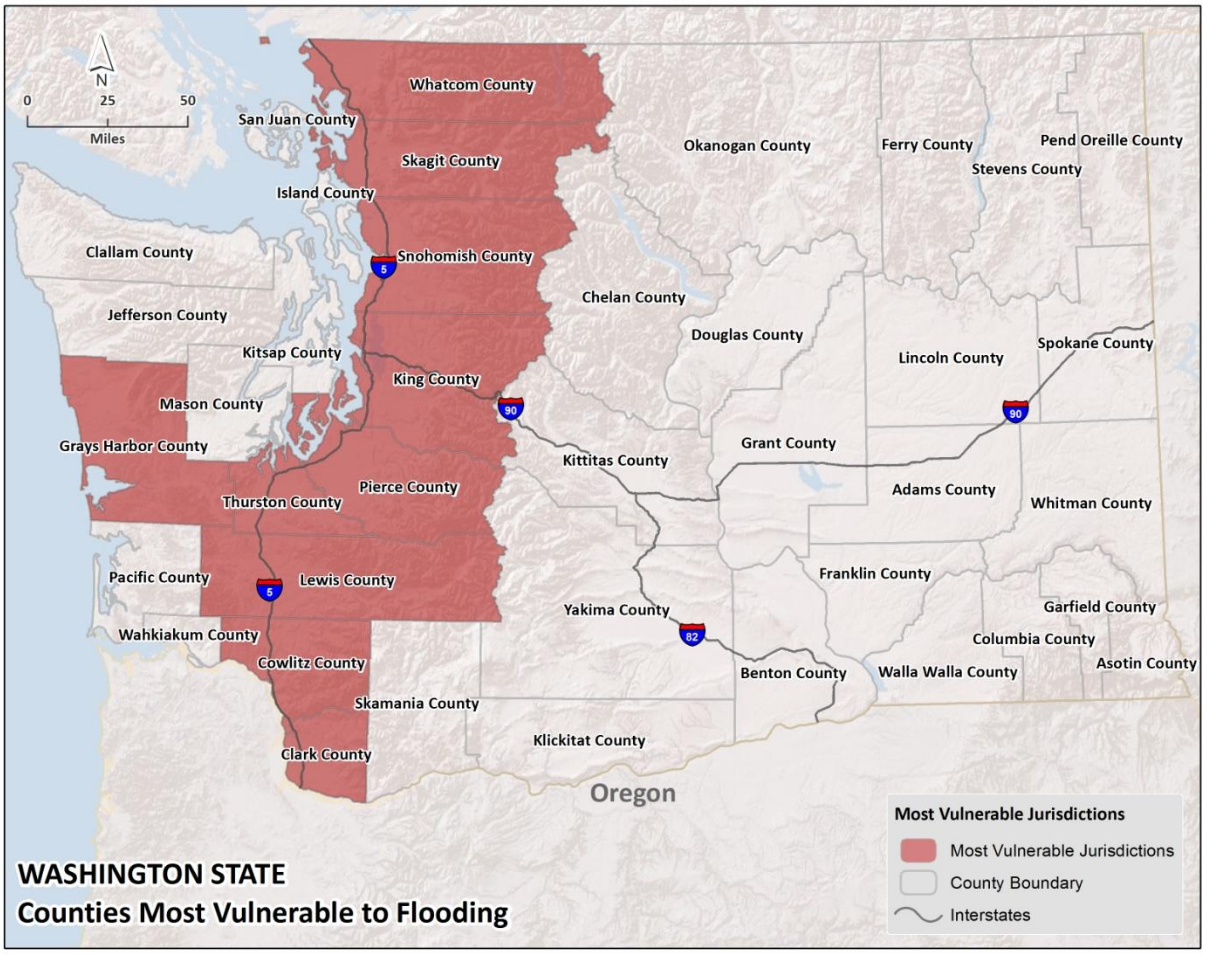
Table 51. Jurisdictional Results

COUNTY	Approx. Frequency of Occurrence	% Area in 1-pct Riverine ACF	Hazus-MH 2.1 GBS Losses	# Flood Insurance Policies	# Flood Insurance Claims	# Repetitive Flood Loss Properties	# SRL Properties	Score
Garfield County	6	2.2	$7,897,000	61	2	-	0	4
Grant County	11	8.1	$189,431,000	353	14	-	0	9
Grays Harbor County	2	9.5	$1,205,714,000	3,721	580	50	2	22
Island County	5	0.6	$20,491,000	1,038	168	9	0	10
Jefferson County	4	2.9	$19,695,000	214	42	3	0	7
King County	2	7.5	$9,765,188,000	9,630	2,775	422	29	28
Kitsap County	4	0.3	$2,111,000	920	105	1	0	10
Kittitas County	4	4.1	$140,146,000	750	245	21	0	14
Klickitat County	4	5.1	$195,911,000	73	24	-	0	9
Lewis County	2	5.7	$678,375,000	2,636	1,965	183	12	25
Lincoln County	6	3.9	$32,822,000	86	13	-	0	5
Mason County	3	3.1	$26,103,000	509	231	29	0	13
Okanogan County	3	2.1	$368,114,000	391	61	2	0	10
Pacific County	3	4.2	$164,442,000	1,392	196	7	0	15
Pend Oreille County	5	2.3	$28,950,000	202	90	2	0	6
Pierce County	3	5.6	$1,873,533,000	3,681	884	125	7	25
San Juan County	6	0.0	N/A	100	4	-	0	4
Skagit County	3	4.0	$156,968,000	5,692	1,100	135	9	24

Table 51. Jurisdictional Results

COUNTY	Approx. Frequency of Occurrence	% Area in 1-pct Riverine ACF	Hazus-MH 2.1 GBS Losses	# Flood Insurance Policies	# Flood Insurance Claims	# Repetitive Flood Loss Properties	# SRL Properties	Score
Skamania County	4	3.7	$192,248,000	71	81	2	0	9
Snohomish County	2	6.0	$1,106,982,000	2,934	1,658	211	18	26
Spokane County	5	3.4	$335,128,000	423	37	1	0	9
Stevens County	6	3.8	$67,918,000	80	11	-	0	5
Thurston County	2	7.5	$327,855,000	997	195	26	3	17
Wahkiakum County	3	6.5	$11,899,000	196	91	13	0	12
Walla Walla County	7	5.5	$122,347,000	304	61	2	0	11
Whatcom County	5	4.2	$235,661,000	2,441	471	48	1	17
Whitman County	3	4.2	$131,023,000	136	53	4	0	11
Yakima County	4	5.0	$1,802,849,000	1,297	275	13	0	15

Figure 63 Counties Most Vulnerable to Flooding



Potential Climate Change Impacts[144,145,146,147,148,149]

Vulnerability to flood hazards is a function of location, type of human activity, use, and frequency of flooding events. The effects of flooding on people and structures can be lessened by total avoidance of flood hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity. Local governments can reduce flooding effects through land-use policies and regulations. Individuals can reduce their exposure to hazards by educating themselves on the past history of a site and by making inquiries to planning and engineering departments of local governments. In addition, it is highly advised to consult the professional services of an engineering geologist, geotechnical engineer, or a civil engineer, who can properly evaluate a site, built or un-built.

Climate change is a slow onset hazard, occurring over a long period of time. To some degree, it is a natural occurrence though evidence suggests that human activity hastens the onset and magnitude of this hazard. It may include conditions such as extreme winter weather or unusual timing of seasonal events that impacts several interrelated systems such as when plants bloom or when streams are fullest. Other factors include increased severity of known hazards. Climate change can exacerbate flooding severity including the depth of water, extent of areas inundated, and the velocity, or force, of the water's flow. In turn, this puts more people and property at risk to flooding and its associated hazards. Sea level rise is also associated with this phenomenon which impacts Washington's coastline.

Sea level rise is defined as the mean rise in sea level. It is thought to be caused by two factors: 1) rising ocean temperature - as the ocean warms, sea water expands in volume; 2) continental ice shelf melt - this increasing the amount of water in the oceans. This leads to a greater area of land being inundated by sea water. NOAA records indicate that sea level has been steadily rising at a rate of 0.04 to 0.1 inches per year since 1900, and further evidence shows this rate is increasing perhaps up to a rate of 0.12 inches per year.[150] The United Nation's Intergovernmental Panel on Climate Change (IPCC) reports that from 1993 to 2003, global sea level rose about 3 millimeters (approximately 0.12 inches) each year, and approximately half of that increase is attributed to the ocean expanding as it warms. While a sea rise of a few millimeters may seem insignificant, Carol Auer, an Oceanographer with the National Oceanic and Atmospheric Administration (NOAA) says, "A half-inch of vertical sea level rise translates to about three feet of land lost on a sandy open coast, due to long term erosion. Moreover, even a slightly higher sea level can cause more dramatic deltas and estuary tides. Rising sea levels also make coastal areas more vulnerable to storm surges, and in turn, to flooding". According to a 2009 NOAA report, historic sea level rise is 0.8 inches per decade in Washington based on data from 1854 to 2006.[151] Climate Central, an independent agency, reported a projected sea level rise of 11 inches by 2050.[152] A 2005 Department of Ecology and University of Washington presentation suggested that areas near Seattle and Tacoma will rise of 1 meter by 2100. Areas near Friday Harbor and Neah Bay were projected to experience a lesser rise of 0.5 meters.[153] Other predictions suggest some areas of the Washington's coastline may experience sea level fall due land being pushed upward along the Cascadia Subduction Zone.[154] As suggested by these studies, sea level rise is a relatively new hazard to be studied lending it to some discrepancy in future projections. The State of Washington has begun to put measures in place to mitigate and decelerate the impacts occurring in the state.

According to a 2005 Governor's report prepared by the Climate Impacts Group titled *Uncertain Future: Climate Change and its Effects on Puget Sound*, from "paleoclimatological evidence, we know that over the history of the earth high levels of greenhouse gas concentrations have correlated with, and to a large extent caused, significant warming to occur, with impacts generated on a global scale." While the report also indicates that the "ultimate impact of climate change on any individual species or ecosystem cannot be predicted with precision," there is no doubt that Washington's climate has demonstrated change.

In July 2007, the Climate Impacts Group launched an unprecedented assessment of climate change impacts on Washington State. *The Washington Climate Change Impacts Assessment* (WACCIA) involved developing updated climate change scenarios for Washington State and using these scenarios to assess the impacts of climate change on the following sectors: agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon, and urban stormwater infrastructure. The assessment was funded by the Washington State Legislature through House Bill 1303.

Also signed 2007 was Executive Order 07-02 Washington Climate Change Challenge. It established goals for reducing greenhouse emissions, creating jobs, and reducing fuels spending. According to the Department of Ecology, it also directed the state to assess steps required to prepare for the impacts of climate change on water supply, public health, agriculture, forestry, and coastal areas.

In 2009, the Washington State Legislature approved the *State Agency Climate Leadership Act* Senate Bill 5560. The Act committed state agencies to lead by example in reducing their greenhouse gas (GHG) emissions to: 15 percent below 2005 levels by 2020; 36 percent below 2005 by 2035; and 57.5 percent below 2005 levels (or 70 percent below the expected state government emissions that year, whichever amount is greater.). The Act, codified in RCW 70.235.050-070, directed agencies to annually measure their greenhouse gas emissions, estimate future emissions, track actions taken to reduce emissions, and develop a strategy to meet the reduction targets. Starting in 2012 and every two years thereafter, each state agency is required to report to Washington State Department of Ecology the actions taken to meet the emission reduction targets under the strategy for the preceding biennium.

Executive Order 09-05 was also passed in 2009, which was called Washington's Leadership on Climate Change. It had several requirements including a strategy to reduce the state's statutory greenhouse gas reduction limits, industry emission benchmarks, and joining West Coast states and the private sector to develop and implement a "West Coast Green Highway."

Recognizing Washington's vulnerability to climate impacts, the Legislature and Governor Chris Gregoire directed state agencies to develop an integrated climate change response strategy to help state, tribal, and local governments, public and private organizations, businesses, and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy*.

Over the next 50 - 100 years, the potential exists for significant climate change impacts on Washington's coastal communities, forests, fisheries, agriculture, human health, and natural disasters. These impacts could potentially include increased annual temperatures, rising sea level, increased sea surface temperatures, more intense storms, and changes in precipitation patterns. Therefore, climate change has the potential to impact the occurrence and intensity of natural disasters, potentially leading to additional loss of life and significant economic losses. Recognizing the global, regional, and local implications of climate change, Washington State has shown great leadership in addressing mitigation through the reduction of greenhouse gases.

Some suggest that there is a better way to deal with floods: the "soft path" to flood risk management. The "soft path" strategy to flood management takes into account the fact that floods will happen and to learn to deal with them the best way possible. This strategy is also based on an understanding that flooding is essential for the health of riverine ecosystems. A "soft path" approach means taking measures to reduce the speed, size, and duration of floods by restoring meanders and wetlands…." This approach "also means doing all we can to get out of floods' destructive path with improved warning and evacuation measures. Such practices are already in use in some parts of the United States and around the world. Improving our ability to cope with floods requires adopting a more sophisticated set of techniques. The "soft path" of flood management should be a core part of efforts to adapt to a changing climate. Such a strategy may reduce deaths due to flooding and could result in much healthier rivers and streams.

At Risk State Facilities to Flood

A Hazus-MH 2.1 analysis was employed to model potential building losses due to flooding for state-owned and state-leased facilities utilizing the Washington State Office of Financial Managements 2012 dataset of state operated facilities.

The analysis for the state owned facilities utilized the 1.0-percent annual chance riverine floodplain data used to determine 1.0-percent annual chance losses (as described above in the Hazus-MH 2.1 Flood Methodology and Results section). State operated facilities were run as Hazus User Defined Facilities. Hazus User Defined Facilities are represented as a point at a specific latitude/longitude location and not as the entire footprint of the building on the ground. Data specific to each building such as elevation, value, area, number of floors, and construction type were utilized in the analysis for each building within Hazus-MH 2.1.

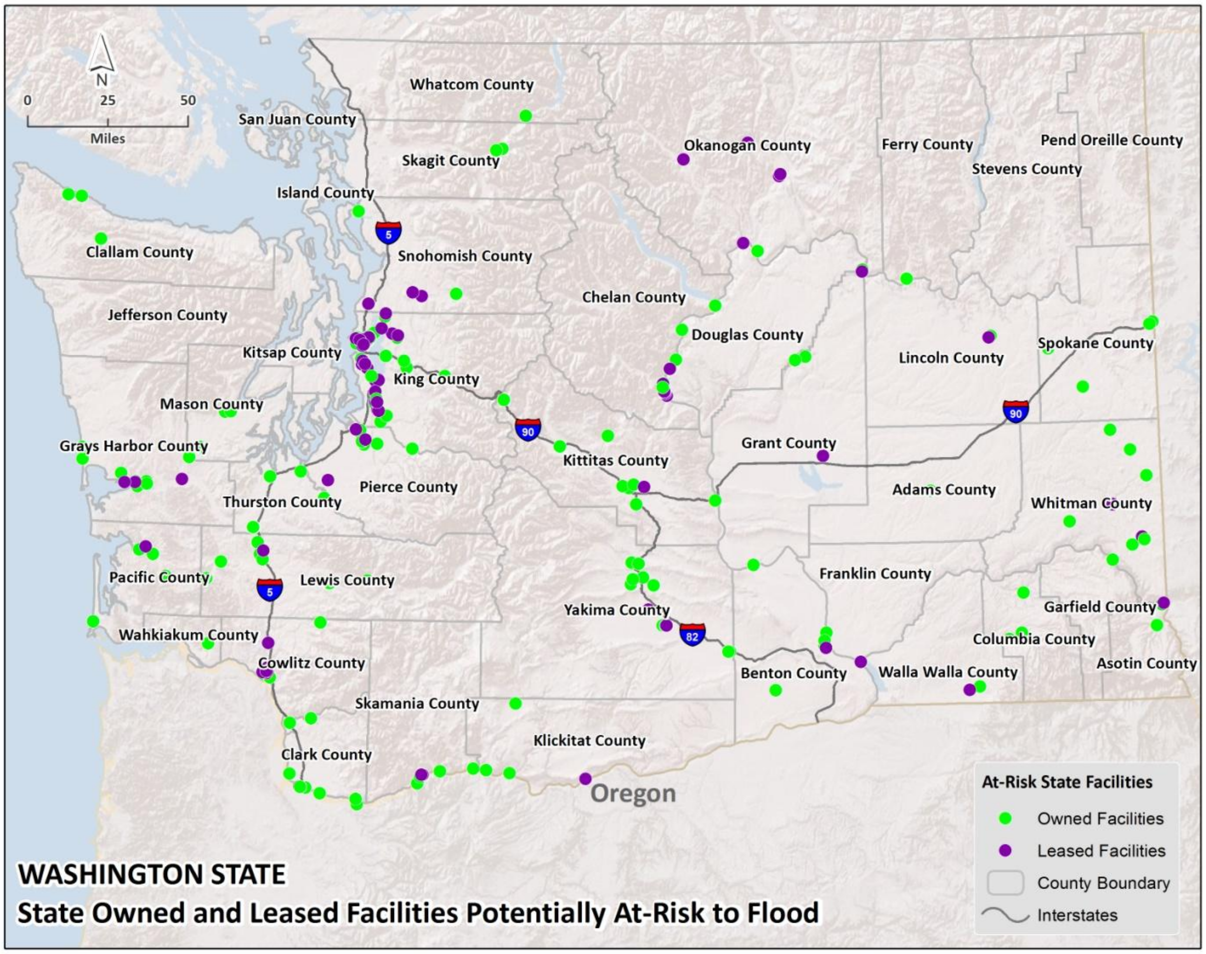
Assumptions were made to the OFM data in order to be used by Hazus as User Defined Facilities. Most critically, building type and building replacement value needed attention. For building type, it was assumed that all structures were one story and constructed of wood. It should be noted that this is not the true building construction of all buildings modeled but was a necessary assumption to analyze the large number of buildings with limited available data. Regarding building replacement value, there were both missing and erroneous data in the OFM data. Therefore, 2012 R.S. Means Facilities Construction Cost data was used to determine building replacement cost using a combination of the building occupancy (Hazus classification of Government buildings (GOV1)), existing building square footage, year built and the assumed building type. Content values were determined based on guidance in the Hazus Technical Manual, which states that GOV1 occupancies have a content value that is equal to the building replacement value. Lastly, it was assumed that each building had an elevation of one foot above the ground (indicating flood level would have to exceed one foot damages).

A total of 9,975 state facilities were analyzed in the state based on Washington State Office of Financial Management (OFM) 2012 dataset of state leased and owned facilities. Their combined estimated replacement value and area was determined to be $13,363,228,000 and 105,060,000 square feet, respectively. Of these buildings, 8,893 were reported as owned and 1,082 were reported as leased. State owned buildings have a combined exposure (building replacement value) of $11,858,700,000 and leased buildings have a combined replacement value of $1,504,528,000. State owned buildings have a combined area of 93,425,000 square feet, and leased buildings have a combined area of 11,635,000 square feet.

Hazus-MH 2.1 was run for the 1.0-percent annual chance riverine floodplain. This analysis found over 1,000 state owned and leased facilities that are potentially at-risk to flooding throughout the state. A majority, 851, are state-owned properties. The state owned facilities have an estimated building loss of approximately $400,208,000 and approximated contents loss of $953,000,000. This results in a loss ratio for building and contents of 10 percent. Leased facilities may experience an estimated building loss of $24,844,000 and content losses of $79,956,000, representing a loss ratio of about 1 percent of the total state operated facilities.

As could be expected, many of these facilities reside in the most vulnerable jurisdictions located in the western portion of the state along the Puget Sound. Additional concentrations are located in southeastern portion of the state, especially Whitman County, and in the middle of the state within Douglas, Kittitas, and Yakima counties. A complete list of the at-risk facilities, including potential damage to the building and contents, is in WA EMD’s possession. A map of those facilities found to be potentially at-risk to the 1.0-percent annual chance flood is depicted in the map below.

Figure 64 State Owned and Leased Facilities At-Risk to the 1.0-percent Annual Chance Riverine Flood



What's Next?

Flood Control Assistance Account Program (FCAAP)
For the 2009-2011 biennium, the Governor's recommended budget included an additional $4 million for flood damage prevention grants. However, due to State revenue shortfalls, this addition was lost along with 50% of the existing FCAAP allocation. Since the need for such funding has been well documented, as FCAAP grant funds requested generally exceed available funds by 400-600%, Ecology hopes to secure additional funding in future biennia. During the next three year planning cycle update (2010 – 2013), Washington State Department of Ecology plans to continue to seek legislative authorization to secure additional funding for the Flood Control Assistance Account Program (FCAAP) to provide more and larger grants for flood hazard mitigation projects.

Although final budgets have yet to be approved by the legislature and the Governor's office (during, the 2013 State Hazard Mitigation Plan Update), indications are that the FCAAP will be reduced 50% again this biennium. That means there will be only $2M in the account, and a competitive grants program will not be offered for the 2013-2015 biennium. There is a possibility that a new capital-budget based fund source for a competitive flood hazard reduction grant program will be approved this session, but that remains to be determined.

FCAAP grants will continue to be coordinated with the State Emergency Management Division's (EMD) operation of their hazard mitigation grants to the fullest extent possible. Staff from each agency will continue to participate in the grant application evaluation process for both FCAAP and the unified HMA grants (including the new National Flood Mitigation program), and other potential funding sources for flood grant projects.

Severe Repetitive Loss (SRL) Program
Ecology and EMD are in the process of developing a strategy to maximize the use of the Severe Repetitive Loss (SRL) Program grant funding. This effort will target the 91 SRLs in the state and will include the use of Increased Cost of Compliance (ICC) funds from the property owners' flood insurance policies. It will include training for local governments, outreach, and coordination with FEMA Region X staff.

Floodplain Management
Ecology is working closely with FEMA Region-X on the implementation of higher standards for the 122 communities in Puget Sound that are under the jurisdiction of the Puget Sound Biological Opinion for Salmon and Orca (BiOp). The BiOp requires implementation of the Reasonable and Prudent measures to ensure that activities under the NFIP do not cause negative impacts to ESA listed species or their critical habitat.

Ecology has joined with EPA, FEMA, NOAA, Puget Sound Partnership, The Nature Conservancy, USACE, and USGS in Floodplains by Design. One of the first projects is to overlay insurance claims, SRL, and RL properties against fish restoration habitat in a GIS environment to identify properties for functional evaluation as future buyout properties that will provide both flood mitigation and fish habitat.[155]

Additionally, the Puget Sound Partnership Action Agenda includes the Protect and Restore Floodplain Function as the Upland and Terrestrial Strategy number A5 in its latest plan. The Action Agenda sets two recovery targets for floodplains in the Puget Sound that it aims to achieve by 2020: 15 percent of degraded floodplain areas are restored or floodplain projects to achieve that outcome are underway across Puget Sound; and No additional loss of floodplain function in any Puget Sound watershed relative to a 2011 baseline.[156]

Other Floodplain Management Initiatives
There is also considerable funding and activity occurring in various parts of the state in regard to flood hazard reduction, including but not limited to; 1) the creation of a new flood wall in the Mt. Vernon area, 2) upgrades, setbacks, and replacement structures in the Green River valley in King County, and 3) a major flood hazard reduction study and related projects in the Chehalis River basin. All of these actions include some level of state funding, running into the tens of millions of dollars.

Risk MAP (Risk Mapping Assessment and Planning)
The purpose behind FEMA's Risk MAP Strategy is to constantly reduce losses to life and property. Flood mapping is used for risk assessments which are incorporated into mitigation plans where risk reduction measures are identified for future action. The top twenty watersheds were analyzed and ranked by risk as part of Risk MAP. The study can be found below in Appendix B. The Lower Skagit, Puget Sound, and Strait of Georgia watersheds ranked highest.

Current Risk MAP activities (as of April 1, 2013) are outlined below:

Table 52. Current Risk MAP activities (as of April 1, 2013)

Project Name	STATUS	Date
Cowlitz - Castle Rock	On-hold	10/31/2011
King County CTP FY09	Active	2/1/2013
Kitsap County Coastal PMR - FY11 (C)	Active	2/27/2014
Snohomish County Coastal PMR - FY11 (C)	Active	2/28/2014
Cowlitz County PAL PMR-FY09 (L)	On-hold	10/31/2012
Cowlitz River-Kelso PAL Cowlitz County PMR-FY09 (L)	On-hold	10/31/2012
Longview PAL Cowlitz County PMR-FY09 (L)	On-hold	10/31/2012
Thornton Creek PMR-FY10 (O)	Active	12/31/2012
Deschutes FY12 (WO) HUC17110016	Active	9/30/2014
Grays Harbor Coastal PMR-FY09-(C)	Active	10/24/2012
Island County Coastal-FY12 (C)	Active	2/26/2015
Kittitas County CW-FY09 (EO)	Active	5/20/2013
Lower Chehalis FY12 (WO) HUC17100104	Active	11/5/2013
Mason County Coastal-CW-FY12 (C)	Active	5/5/2014
Naches-Yakima County-FY10 (W)-HUC17030002	Active	10/31/2014
Pacific County CW Coastal-FY09 (C)	Active	5/10/2013
Pierce County Coastal PMR- FY-11 (C)	Active	12/30/2013
Salish Sea Coastal FY 12 (C)	Active	

Washougal PAL-Clark County PMR-FY09 (L)	On-hold	9/28/2012
Skagit Co. Coastal PMR-FY12 (C)	Active	2/21/2015
Thurston County Coastal PMR-FY11 (C)	Active	1/15/2014
White River-Pierce County PMR-FY09 (OE)	On-hold	6/30/2013
Whatcom County Coastal PMR-FY12 (C)	Active	2/14/2015
Whitman County CW-FY09 (EO)	On-hold	12/27/2012
Woodland PAL Cowlitz County PMR-FY09 (L)	On-hold	10/31/2012

Flood Hazard Profile Appendix A[157]

NFIP Loss Statistics by Washington State Jurisdictions
1978 through January 31, 2013

LOSS STATISTICS
WASHINGTON
AS OF 01/31/2013

COUNTY NAME	COMMUNITY NAME	TOTAL LOSSES	CLOSED LOSSES	OPEN LOSSES	CWOP LOSSES	TOTAL PAYMENTS
ADAMS COUNTY	LIND, TOWN OF	1	1	0	0	18,431.39
	RITZVILLE, CITY OF	3	2	0	1	6,545.26
	WASHTUCNA, TOWN OF	1	1	0	0	2,241.04
ASOTIN COUNTY	ASOTIN COUNTY*	3	3	0	0	15,664.29
BENTON COUNTY	BENTON CITY, TOWN OF	20	15	0	5	211,461.44
	BENTON COUNTY *	45	35	0	10	613,792.45
	KENNEWICK, CITY OF	4	2	0	2	7,288.30
	PROSSER, CITY OF	1	1	0	0	8,154.30
	RICHLAND, CITY OF	17	11	0	6	175,651.79
	WEST RICHLAND, TOWN OF	10	9	0	1	207,335.97
CHELAN COUNTY	CASHMERE, CITY OF	7	1	0	6	7,976.50
	CHELAN COUNTY *	99	74	0	25	975,185.13
	LEAVENWORTH, CITY OF	4	3	0	1	87,000.27
	WENATCHEE, CITY OF	18	6	0	12	5,093.37
CLALLAM COUNTY	CLALLAM COUNTY *	85	47	0	38	950,517.16
	FORKS, CITY OF	1	1	0	0	2,556.64
	PORT ANGELES, CITY OF	10	6	0	4	78,283.49
	SEQUIM, CITY OF	7	2	0	5	55,797.74
CLARK COUNTY	BATTLE GROUND, CITY OF	3	2	0	1	3,265.40
	CAMAS, CITY OF	4	3	0	1	13,710.27
	CLARK COUNTY *	102	77	0	25	1,666,659.68
	VANCOUVER, CITY OF	9	4	0	5	101,610.40
	WASHOUGAL, CITY OF	10	8	0	2	71,369.59
	WOODLAND, CITY OF	69	51	0	18	988,025.89
COLUMBIA COUNTY	COLUMBIA COUNTY*	2	1	0	1	7,903.48
	DAYTON, CITY OF	36	25	0	11	141,396.90
	STARBUCK, CITY OF	1	0	0	1	.00
COWLITZ COUNTY	CASTLE ROCK, CITY OF	29	22	0	7	616,450.54
	COWLITZ COUNTY *	411	346	0	65	8,988,647.84
	KALAMA, CITY OF	3	3	0	0	93,973.60
	KELSO, CITY OF	49	38	0	11	820,639.15
	LONGVIEW, CITY OF	40	24	0	16	366,434.48
DOUGLAS COUNTY	DOUGLAS COUNTY *	3	3	0	0	20,029.18
FERRY COUNTY	FERRY COUNTY *	2	1	0	1	11,770.96
FRANKLIN COUNTY	FRANKLIN COUNTY *	1	0	0	1	.00
GARFIELD COUNTY	POMEROY, CITY OF	2	1	0	1	94.98
GRANT COUNTY	EPHRATA, CITY OF	12	2	0	10	9,100.42
	GRANT COUNTY*	1	1	0	0	2,423.42
	MOSES LAKE, CITY OF	1	1	0	0	1,776.84
GRAYS HARBOR COUNTY	ABERDEEN, CITY OF	221	144	1	76	686,941.00
	COSMOPOLIS, CITY OF	3	3	0	0	2,021.76
	ELMA, CITY OF	18	18	0	0	487,641.12
	GRAYS HARBOR COUNTY*	210	188	1	21	4,413,813.63
	HOQUIAM, CITY OF	76	53	2	21	412,631.25
	MONTESANO, CITY OF	15	14	0	1	195,095.97
	OAKVILLE, CITY OF	8	8	0	0	231,456.51
	OCEAN SHORES, CITY OF	22	12	0	10	194,080.31
	WESTPORT, CITY OF	12	7	0	5	96,860.90
ISLAND COUNTY	ISLAND COUNTY *	182	115	15	52	1,193,738.33
	LANGLEY, CITY OF	2	0	0	2	.00
JEFFERSON COUNTY	JEFFERSON COUNTY *	34	22	1	11	316,932.41
	PORT TOWNSEND, CITY OF	9	4	0	5	26,687.08

KING COUNTY	AUBURN, CITY OF	10	6	0	4	43,341.02
	BELLEVUE, CITY OF	45	31	1	13	535,787.38
	BOTHELL, CITY OF	10	7	0	3	33,665.27
	BURIEN, CITY OF	17	10	0	7	84,053.59
	CARNATION, CITY OF	26	21	0	5	786,646.68
	DES MOINES, CITY OF	4	4	0	0	211,934.98
	DUVALL, CITY OF	4	4	0	0	146,511.59
	ENUMCLAW, CITY OF	3	3	0	0	69,500.65
	FEDERAL WAY, CITY OF	1	0	1	0	.00
	ISSAQUAH, CITY OF	148	123	0	25	3,974,505.06
	KENMORE, CITY OF	1	1	0	0	14,697.30
	KENT, CITY OF	31	12	0	19	129,404.88
	KING COUNTY*	1,175	954	11	210	21,277,014.81
	KIRKLAND, CITY OF	7	4	0	3	44,518.84
	LAKE FOREST PARK, CITY OF	4	1	0	3	1,886.44
	MERCER ISLAND, CITY OF	5	1	0	4	6,952.20
	MILTON, CITY OF	4	4	0	0	70,379.73
	NORMANDY PARK, CITY OF	7	3	0	4	13,978.43
	NORTH BEND, CITY OF	78	61	0	17	985,053.86
	PACIFIC, CITY OF	25	24	0	1	436,228.15
	REDMOND, CITY OF	10	4	0	6	21,542.88
	RENTON, CITY OF	17	10	0	7	84,974.92
	SAMMAMISH, CITY OF	2	2	0	0	41,996.22
	SEATAC, CITY OF	1	1	0	0	1,319.24
	SEATTLE, CITY OF	197	107	13	77	1,443,105.21
	SHORELINE, CITY OF	1	1	0	0	4,021.74
	SKYKOMISH, TOWN OF	18	18	0	0	304,215.24
	SNOQUALMIE, CITY OF	950	866	0	84	17,963,766.70
	TUKWILA, CITY OF	3	1	0	2	1,309.89
KITSAP COUNTY	BAINBRIDGE ISLAND, CITY OF	8	4	2	2	96,975.25
	BREMERTON, CITY OF	7	5	0	2	8,905.60
	KITSAP COUNTY *	98	51	4	43	1,503,205.62
KITTITAS COUNTY	CLE ELUM, CITY OF	13	10	0	3	205,420.05
	ELLENSBURG, CITY OF	26	18	0	8	195,494.80
	KITTITAS COUNTY *	194	159	1	34	2,208,149.14
	KITTITAS, TOWN OF	11	5	0	6	8,610.64
	SOUTH CLE ELUM, CITY OF	1	1	0	0	8,374.12
KLICKITAT COUNTY	GOLDENDALE, CITY OF	1	1	0	0	4,595.36
	KLICKITAT COUNTY *	23	21	0	2	305,085.56
LEWIS COUNTY	CENTRALIA, CITY OF	717	668	1	48	25,448,455.26
	CHEHALIS, CITY OF	511	445	4	62	28,085,458.58
	LEWIS COUNTY *	729	638	4	87	22,605,362.81
	MORTON, CITY OF	1	0	0	1	.00
	PE ELL, TOWN OF	1	1	0	0	37,770.81
	TOLEDO, CITY OF	4	3	0	1	75,538.10
	WINLOCK, TOWN OF	2	1	0	1	859.31
LINCOLN COUNTY	ALMIRA, TOWN OF	2	1	0	1	3,338.05
	SPRAGUE, CITY OF	8	6	0	2	95,694.71
	WILBUR, TOWN OF	2	1	0	1	2,477.83
MASON	SKOKOMISH INDIAN TRIBE	1	1	0	0	728.40
MASON COUNTY	MASON COUNTY*	222	185	3	34	3,652,659.75
	SHELTON, CITY OF	12	8	0	4	132,510.12
OKANOGAN COUNTY	BREWSTER, TOWN OF	1	1	0	0	4,700.29
	OKANOGAN COUNTY *	30	19	0	11	268,266.87
	OKANOGAN, CITY OF	13	9	0	4	31,871.31
	OMAK, CITY OF	5	5	0	0	65,180.53
	OROVILLE, TOWN OF	9	6	0	3	12,179.27
	PATEROS, TOWN OF	1	0	0	1	.00
	TONASKET, TOWN OF	1	0	0	1	.00
	WINTHROP, TOWN OF	1	0	0	1	.00
PACIFIC COUNTY	ILWACO, TOWN OF	4	2	0	2	4,595.09
	LONG BEACH, TOWN OF	1	1	0	0	5,025.50
	PACIFIC COUNTY *	136	96	0	40	2,379,071.20
	RAYMOND, CITY OF	39	35	0	4	262,004.67
	SOUTH BEND, CITY OF	16	11	0	5	54,878.72
PEND OREILLE COUNTY	CUSICK, TOWN OF	3	3	0	0	70,646.02
	METALINE, TOWN OF	1	1	0	0	1,907.32
	NEWPORT, CITY OF	2	2	0	0	28,451.57
	PEND OREILLE COUNTY *	84	75	0	9	1,214,555.92
PIERCE COUNTY	BONNEY LAKE, CITY OF	2	2	0	0	8,753.69
	BUCKLEY, CITY OF	5	4	0	1	127,368.45
	FIFE, CITY OF	4	3	0	1	19,232.23
	FIRCREST, CITY OF	12	8	0	4	79,427.69
	GIG HARBOR, TOWN OF	2	1	0	1	2,375.03
	ORTING, TOWN OF	32	22	0	10	345,247.27
	PIERCE COUNTY*	515	418	9	88	11,233,945.06
	PUYALLUP, CITY OF	90	69	0	21	2,729,905.04
	SOUTH PRAIRIE, TOWN OF	18	15	0	3	198,616.37
	STEILACOOM, TOWN OF	2	2	0	0	12,279.65
	SUMNER,CITY OF	132	112	2	18	3,879,810.24
	TACOMA, CITY OF	80	60	0	20	1,350,952.61
	WILKESON, TOWN OF	3	3	0	0	36,351.45
SAN JUAN COUNTY	SAN JUAN COUNTY*	4	2	0	2	26,407.09

SKAGIT COUNTY	BURLINGTON, CITY OF	30	16	0	14	45,650.94
	CONCRETE, TOWN OF	15	12	0	3	93,078.44
	HAMILTON, TOWN OF	224	198	0	26	3,911,359.77
	LA CONNER, TOWN OF	5	2	0	3	2,664.54
	MOUNT VERNON, CITY OF	98	62	0	36	590,616.19
	SEDRO- WOOLLEY, CITY OF	35	29	0	6	336,318.68
	SKAGIT COUNTY *	693	563	2	128	7,272,877.18
SKAMANIA COUNTY	SKAMANIA COUNTY *	79	72	0	7	1,350,490.20
	STEVENSON, TOWN OF	2	2	0	0	19,363.38
SNOHOMISH COUNTY	ARLINGTON, CITY OF	8	8	0	0	202,257.57
	BRIER, CITY OF	3	1	0	2	9,680.81
	DARRINGTON, TOWN OF	3	1	0	2	132,901.34
	EDMONDS, CITY OF	18	13	0	5	334,295.64
	EVERETT, CITY OF	13	8	1	4	219,839.71
	GOLD BAR, CITY OF	1	1	0	0	1,002.24
	GRANITE FALLS, CITY OF	1	0	0	1	.00
	INDEX, TOWN OF	36	30	0	6	715,457.38
	LAKE STEVENS, CITY OF	4	3	0	1	17,059.83
	LYNNWOOD, CITY OF	25	22	2	1	948,012.99
	MARYSVILLE, CITY OF	9	6	0	3	50,552.17
	MONROE, CITY OF	66	60	0	6	784,316.21
	MOUNTLAKE TERRACE, CITY OF	5	4	0	1	51,411.08
	MUKILTEO, CITY OF	4	1	1	2	4,015.00
	SNOHOMISH COUNTY *	1,203	985	9	209	18,905,849.63
	SNOHOMISH, CITY OF	54	47	0	7	1,040,420.33
	STANWOOD, CITY OF	35	23	0	12	412,078.64
	SULTAN, CITY OF	183	162	0	21	2,617,572.12
SPOKANE COUNTY	CHENEY, CITY OF	1	0	0	1	.00
	MEDICAL LAKE, CITY OF	1	0	0	1	.00
	SPANGLE, CITY OF	4	4	0	0	193,449.23
	SPOKANE COUNTY*	19	11	0	8	191,360.20
	SPOKANE, CITY OF	12	9	0	3	112,978.89
STEVENS COUNTY	CHEWELAH, CITY OF	6	2	0	4	5,079.58
	STEVENS COUNTY *	5	4	0	1	45,526.41
THURSTON COUNTY	BUCODA, TOWN OF	43	38	0	5	257,010.48
	LACEY, CITY OF	3	1	0	2	8,088.08
	OLYMPIA, CITY OF	20	16	0	4	369,197.88
	TENINO, CITY OF	7	7	0	0	105,231.94
	THURSTON COUNTY *	220	173	3	44	3,466,400.57
	TUMWATER, CITY OF	2	2	0	0	12,514.40
	YELM, CITY OF	2	1	0	1	7,602.70
WAHKIAKUM COUNTY	CATHLAMET, TOWN OF	1	1	0	0	4,906.03
	WAHKIAKUM COUNTY *	92	75	3	14	1,682,803.69
WALLA WALLA COUNTY	COLLEGE PLACE, CITY OF	1	1	0	0	4,259.05
	WAITSBURG, CITY OF	31	25	0	6	394,036.41
	WALLA WALLA COUNTY *	29	21	0	8	315,907.64
WHATCOM COUNTY	BELLINGHAM, CITY OF	26	19	0	7	659,075.54
	BLAINE, CITY OF	2	2	0	0	22,115.36
	EVERSON, CITY OF	46	38	0	8	426,052.24
	FERNDALE, CITY OF	37	29	0	8	1,048,432.06
	LUMMI INDIAN RESERVATION	9	6	2	1	141,846.11
	LYNDEN, CITY OF	4	4	0	0	16,134.99
	NOOKSACK, CITY OF	2	1	0	1	1,843.30
	SUMAS, CITY OF	66	53	0	13	757,631.16
	WHATCOM COUNTY *	288	220	4	64	3,630,254.53
WHITMAN COUNTY	ALBION, TOWN OF	4	4	0	0	38,033.66
	ENDICOTT, TOWN OF	1	1	0	0	1,432.85
	GARFIELD, TOWN OF	2	2	0	0	24,665.92
	PALOUSE, CITY OF	8	4	0	4	262,593.41
	PULLMAN, CITY OF	29	22	0	7	136,666.04
	ROSALIA, TOWN OF	3	1	0	2	9,183.40
	WHITMAN COUNTY *	6	3	0	3	1,956.71
YAKIMA COUNTY	NACHES, CITY OF	4	2	0	2	27,324.86
	SELAH, CITY OF	48	44	0	4	699,673.04
	SUNNYSIDE, CITY OF	1	0	0	1	.00
	TOPPENISH, CITY OF	8	7	0	1	43,550.02
	UNION GAP, CITY OF	1	1	0	0	3,290.80
	WAPATO, CITY OF	8	7	0	1	30,433.06
	YAKIMA COUNTY *	195	139	0	56	1,011,645.03
	YAKIMA, CITY OF	10	5	0	5	14,963.69
TOTAL FOR WASHINGTON		12,743	10,261	103	2,379	239,738,441.71

Source: FEMA Claim Information by State, 1978 to 2013. Available at: http://bsa.nfipstat.fema.gov/reports/1040.htm#53

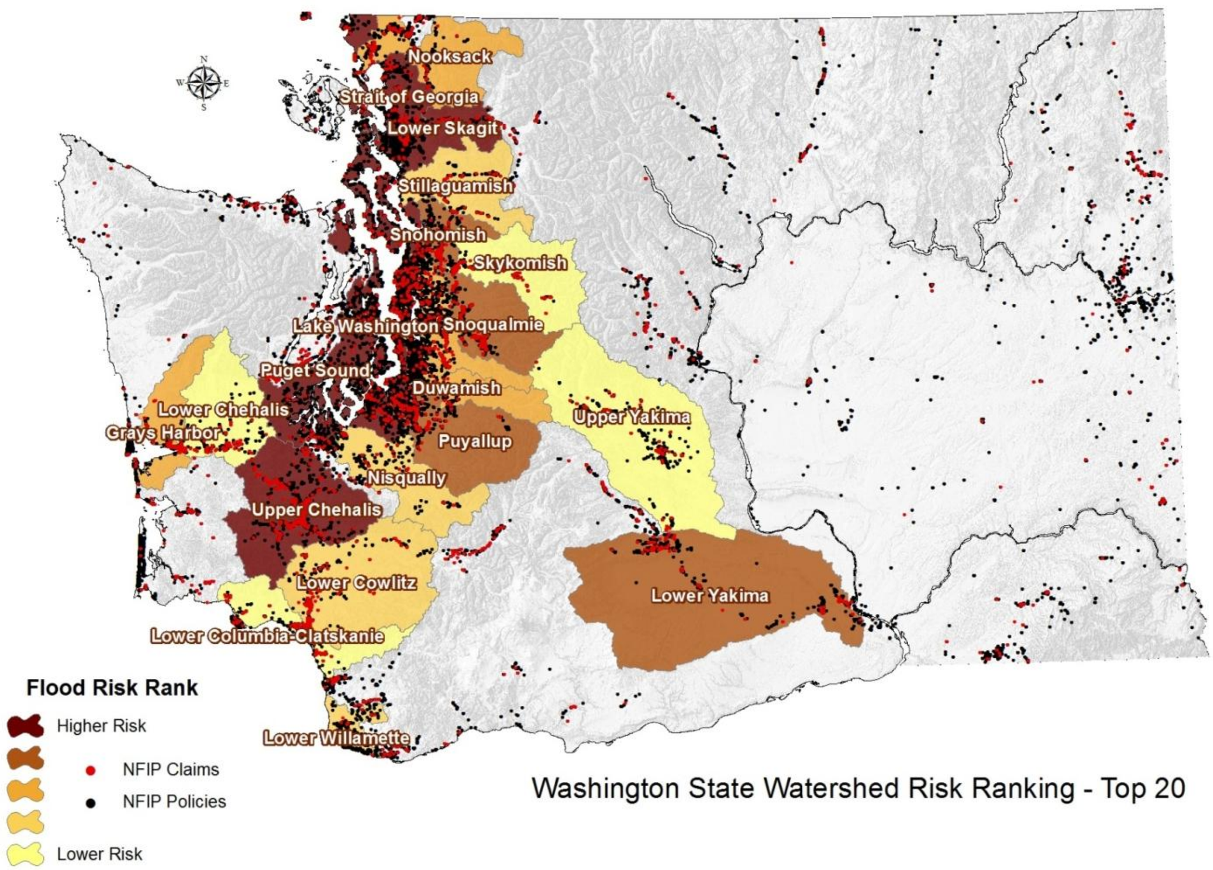
Flood Hazard Profile Appendix B

Department of Ecology Washington State Watershed Risk Assessment (2012)

Washington State Watershed Risk Assessment

Introduction

This Risk Assessment is a product of Washington State's Business planning process that heavily engages in digital and spatial platforms to assess flood hazards that provide instant quantitative information spatially across the state with dynamic capabilities to assess evolving risks. The purpose of this Risk Assessment is to provide a valuable planning and sequencing tool to the FEMA-WA State partnership. This Assessment was developed and delivered in GIS database with searchable tables, links to dynamic tables for editing and updating attribute data, and database-driven mapping. This study was completed by the State of Washington Department of Ecology and analyzes flood risk based on watershed available in the western portion of the state.



Risk Assessment Factors

Three risk assessment factors were developed and assigned to FEMA's standard Hydrologic Unit Code (HUC), specifically, the HUC8 level watersheds:

Population Density 60%

NFIP Policies & Claims 30%

Floodplain Area 10%

FEMA provided total population values by watershed from Federal Census data. The State recalculated total population values into population density values by watershed area and generated an attribute in the HUC8 GIS spatial data table representing population density.

FEMA also provided NFIP policies and claims data in a spatial point file feature with attribute tables. The State spatially joined NFIP policies point features to the HUC8 watershed data table as an attribute of total policies and claims per watershed.

The State generated the floodplain area attribute by intersecting FEMA's Q3 data with the HUC8 watershed spatial data and calculated the percent floodplain to watershed area in the attribute table.

Watershed Ranking

Total numbers and areas were avoided and a weighted scheme was developed to emphasize risk factors with greater influence on risk concentrations. Population density was assigned a sixty percent weight as the predominate risk factor. NFIP policies and claims were allocated thirty percent weighted value and floodplain area given ten percent of the scheme.

The weighted method was removed and equal quantities were ranked to evaluate the sensitivity if the weighted approach. All top twenty watersheds remained in the top twenty with emphasis given to large unpopulated floodplain deltas and understated the value of population density as a predominate risk factor.

All three weighted factors were sorted in ascending order and assigned a value from one to seventy one with the highest risk watersheds assigned the lowest values. The three rankings were summed equally and again assigned a rank value with the highest risk watersheds assigned the lowest values. The resulting assessment assigned a value to all seventy-one watersheds.

The top twenty at-risk watersheds are detailed below.

Table 53 HUC8 Name	Pop 2010	Trifecta Rank	FP Area Rank	Pop Density Rank	Policies Claims Rank	Topo	Discovery	Final weighted rank	Map Page
Lower Skagit	70102	30	2	11	1	yes	coastal	1	5
Puget Sound	1512450	4	17	3	3	yes	coastal	2	7
Strait of Georgia	96930	22	7	9	9			3	9
Upper Chehalis	90534	9	3	22	2	yes	riverine	4	11
Snohomish	233826	23	18	4	15	yes		5	13
Puyallup	255521	2	23	8	6	yes		6	15
Lower Yakima	287260	7	4	14	17	yes		7	17
Snoqualmie	67487	18	21	15	4	yes	coastal	8	19
Grays Harbor	34964	29	13	23	7	yes	coastal	9	21
Duwamish	379604	12	42	5	5		coastal	10	23
Lake Washington	1329140	6	45	1	8	yes		11	25
Nooksack	64635	16	11	18	19	yes	riverine	12	27
Stillaguamish	51139	21	20	21	11	yes	coastal	13	29
Nisqually	87525	13	22	12	25	yes	riverine	14	31
Lower Willamette	181920	99	28	7	27	yes		15	33
Lower Chehalis	32212	17	6	29	21	yes		16	35
Lower Cowlitz	58735	28	19	28	13	yes	levee	17	37
Lower Columbia-Clatskanie	38200	10	29	26	16	yes		18	39
Upper Yakima	59460	11	15	36	18	yes	riverine	19	41
Skykomish	28652	19	33	33	10	yes		20	43

Lower Skagit Watershed
Risk MAP Rank: 1 of 67

Table 54 HUC8 Name	Sq miles	Trifect a Rank	Floodplain SQ Miles	Floodplain area Rank	Pop density Rank	Policies & Claims Rank	Risk MAP Rank
Lower Skagit	454	30	89	2	11	1	1

Communities: Burlington, Concrete, Hamilton, La Conner, Lyman, Mount Vernon, Sedro-Woolley, Stanwood

Principal Flood Problems: Skagit River

Flooding from the Skagit River affects the cities of Burlington, Mount Vernon and Sedro Woolley, the Towns of Hamilton, Lyman, La Conner and the unincorporated areas of Skagit County. Flooding problems occur from high-tide levels in Skagit Bay or from major floods on the Skagit River and its tributaries. Tidal flooding can occur when a high astronomical tide is heightened by a large storm surge. Wave run-up is a significant factor in areas where the shorelines are not sheltered from local wind effects.

Major floods of the Skagit River and its tributaries are caused by winter rainstorms. The Skagit basin, lying directly in the storm path of cyclonic disturbances from the Pacific Ocean, is subject to numerous storms, which are frequently quite severe. Not uncommon are two or more storms in rapid succession, sometimes less than 24 hours apart. Rain-type floods usually occur in November or December, but may occur as early as October or as late as February. These floods are characterized by sharply rising river flows, high magnitude peaks, and flood durations of several days. Often, heavy rainfall is accompanied by snowmelt which increases the runoff. On the mountain slopes, storm precipitation is heavy and almost continuous as a result of combined frontal and orographic effects.

Earlier levee construction was to provide protection from spring floods which permit ted farmers to plant earlier. These levees were subsequently improved to also provide more winter protection.

The Skagit River represents the major flooding source of the delta area. Flooding occurs from multiple levee failures and bank and levee overtopping during a 100-year flood. Downstream of Sedro Woolley, the Skagit River flows through a large delta area that fronts Samish, Padilla, and Skagit Bays. Within this area, the floodplain forms a large alluvial fan with an east-west width of approximately 11 miles and a north-south width of 19 miles. The most severe floods and the corresponding peak discharges since 1908, when stream gauging in the Skagit River Basin began.

Puget Sound Watershed
WA Risk MAP Rank: 2 of 67

Table 55 HUC8_Name	Sq miles	Trifecta Rank	Floodplain SQ Miles	Foodplain Area Rank	Pop density Rank	Policies & Claims Rank	Risk Rank
Puget Sound	1492	4	40.5	17	3	3	2

Communities: Anacortes, Bainbridge Island, Bremerton, Burien, Coupeville, Des Moines, DuPont, Edgewood, Edmonds, Everett, Federal Way, Fife, Fircrest, Gig Harbor, Kent, Lacey, Lakewood, Langley, Lynnwood, Marysville, Milton, Milton, Mukilteo, Normandy Park, Oak Harbor, Olympia, Olympia, Olympia, Port Orchard, Port Townsend, Poulsbo, Puyallup, Ruston, SeaTac, Seattle, Shelton, Shoreline, Steilacoom, Tacoma, Tumwater, University Place, Woodway

Principal Flood Problems
Population is the biggest risk factor in the Puget Sound Basin. Coastal flooding rarely causes damages without riverine influences. Flooding problems occur from high-tide levels in Puget Sound combined with high flows from riverine systems and concentrated low pressure storms. Low lying populated areas of Puget Sound, sloughs, and areas exposed to westward wind fetch experience the highest flood risk. Typical examples are the cities of Olympia and La Connor, the Skokomish and Skagit deltas, and coastal areas of Island and San Juan Counties.

Groundwater Flooding
The unique geomorphic history of Puget Sound, Washington, leads to the unusual phenomenon of ground-water flooding when wet conditions persist for much more than a year. In the central Pierce County area of Southern Puget Sound, some relic drainage channels — legacies of melting glaciers at the conclusion of the last Ice Age — now convey only ground water. When wet conditions prevail, ground-water flooding can be observed moving progressively "downstream" in these channels.

Cost of Flooding in Western Washington
More than 28,000 structures have been built in floodplains since the National Flood Insurance Program's inception. Since 1990, the costs of flooding in Western Washington have been have been disastrous and costly for all of us. Puget Sound has experienced 16 federally declared flood disasters. 58 lives have been lost due to floods. More than $1.4 billion in flood damages have been paid by taxpayers. Levees failed or overtopped in ten of the past 16 flood disasters, costing $125 million in repairs to more than 200 sites. 833 homes in the Puget Sound Area have flooded repeatedly (three times or more), and cost taxpayers $71 million in insurance claims. Interstate 5 has been closed four times costing more than $181 million in losses. In a single 1990 flood, more than 600 cattle died in Snohomish and King Counties. In a 2003 flood, more than 300 farm animals perished.

Strait of Georgia Watershed
WA Risk MAP Rank: 3 of 67

Table 56 HUC8 name	Sq. miles	FEMA Trifecta Rank	Floodplain SQ Miles	Floodplain Area Rank	Pop Density Rank	Policies & Claims Rank	Risk Rank
Strait of Georgia	440.84	22	58.8	7	9	9	3

Communities: Blaine, Ferndale, Bellingham, Sedro-Woolley, Anacortes, Burlington

Primary Flooding Sources: Whatcom Creek, Friday Creek, Samish River, Samish River, Strait of Georgia

Principal Flood Problems
Flood damage in the coastal areas of Whatcom County is caused by a combination of high tide levels and wave action. The observed tide level is a result of astronomical tide (caused by gravitational effects of sun and moon) and storm surge (rise in water levels as a result of wind stress and low atmospheric

pressure). Waves, breaking onto the shoreline, produce an additional water level rise at the beach (wave setup), and waves running up the beach (wave run-up) can cause impact damage far above the stillwater level. Flood elevations were determined by combining the effects of tide and wave setup. When both calculated wave heights at the shoreline and wave run-up exceeded 3 feet, a wave hazard area was denoted in the region between the 1-percent-annual-chance flood elevation and the estimated limits of wave run-up.

Coastal Flooding in the Cities of Bellingham and Blaine Flood damage in the coastal areas of Bellingham and Blaine is caused by a combination of high tide levels and wave action. The observed tide level is a result of astronomical tide (caused by gravitational effects of the sun and moon) and storm surge (rise in water levels due to wind stress and low atmospheric pressure). Waves breaking onto the shoreline produce an additional water-level rise at the beach (wave setup), and waves running up the beach (wave run-up) can cause impact damage far above the stillwater level. Flood elevations were determined by combining the effects of tide and wave setup.

Upper Chehalis Watershed
WA Risk MAP Rank: 4 of 67

Table 57 HUC8 Name	Sq Miles	FEMA Trifecta Rank	Floodplain SQ Miles	Floodplain Density Rank	population Density Rank	Policies & Claims Rank	Risk Rank
Upper Chehalis	1299	9	85.1	3	22	2	4

Communities: Bucoda, Centralia, Chehalis, Napavine, Oakville, Pe Ell, Tenino, Tumwater

Primary Flooding Sources: Black River, Chehalis River, Middle Fork, Newaukum River, North Fork Newaukum River, Skookumchuck River, South Fork Chehalis River, South Fork Newaukum River

Principal Flood Problems:
The Chehalis River Basin of western Washington is the second largest in the state, second only to the Columbia Basin. In the last two decades, four 100-year floods have occurred there: in January and November 1990, February 1996, and December 2007. Extreme flood events along the Centralia Reach have severely impacted transportation. In 1990, I-5 was closed for one day; in 1996, four days; and in 2007, four days. In 2004 the Army Corps estimated that transportation-delay costs for the freeway were 3.4 million dollars per day of closure, and that a 100-year flood could be expected to bring 4.5 days of closure costing 15.3 million dollars.

Federal Involvement
There is a long history of government flood projects, studies, and proposals in the basin, with particular focus on the flood-prone Centralia Reach of the upper river, near the Twin Cities of Lewis County, Centralia, and Chehalis. In 1931, 1935, and 1944 Army Corps reports on the basin determined that flood control was not feasible. In 1965 a federal study began that determined large-scale projects were not justified, though levees, channel modifications, and headwater dams may be. In 1972 interim reports were published, and beginning in 1974 a levee alternative was evaluated for the Centralia area. In 1982 a U.S. Army Corps feasibility study recommended increasing storage of the Skookumchuck Reservoir on the Skookumchuck River, a tributary which joins the Chehalis River near Centralia. Preconstruction engineering and design began in 1988; work was suspended in 1991, when the project was determined unfeasible; and a final report was released in 1992.

Snohomish Watershed
WA Risk MAP Rank: 5 of 67

Table 58 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Snohomish	291.5	23	40.3	18	4	15	5

Communities: Arlington, Everett, Granite Falls, Lake Stevens, Marysville, Mill Creek, Monroe, Snohomish

Primary Flooding Sources: Snohomish River, Pilchuck River, Snoqualmie River

Principal Flood Problems
Flooding in the Snohomish watershed may occur from high tide levels in Puget Sound or from floods on the various rivers and streams in the county. Tidal flooding can occur when a high astronomical tide (gravitational effects of the sun and moon) is heightened by a large storm surge (rise in water levels due to wind stress and low atmospheric pressure). Wave run-up is a significant factor when occurring during high-tide conditions in areas where the shorelines are not sheltered from local wind effects. Major floods on rivers and streams in Snohomish County are caused by rainstorms between October and March. Though floodwaters are primarily from rainfall, they are often augmented by snowmelt. Snowmelt floods in spring and summer months are usually not as severe. Rain-runoff floods in the study basins are characterized by sharply rising riverflows, with high-magnitude peaks and flood durations ranging from a few hours on small streams to several days on larger rivers. The greatest threat from flooding occurs between late November and early February, when moisture-laden storms pass through the Puget Sound region. Characteristically, these storms are 24 hours in duration, with moderate and fairly constant precipitation seldom exceeding 1 inch per hour. Not uncommon are two or more storms in rapid succession, sometimes less than 24 hours apart. The Snohomish River floodplain is subject to frequent inundation. Except for the French Creek Drainage District, existing levees provide protection only from normal spring floods that would damage crops. Overtopping maybe expected every 2 to 5 years on average, depending on height and condition of levees. Streamflow records are available from two gaging stations operated by the USGS on the Snohomish River. The gaging station on the Snohomish River near the City of Monroe is located approximately 0.1 mile downstream of the Skykomish and Snoqualmie River confluence and has operated since 1963. Records for the gage at the City of Snohomish included both stage and discharge between 1942 and 1965, but since 1965 only stages are available through the USGS.

Puyallup Watershed
WA Risk MAP Rank: 6 of 67

Table 59 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Puyallup	984.7	2	33.0	23	8	6	6

Communities: Algona, Auburn, Bonney Lake, Buckley, Carbonado, Edgewood, Enumclaw, Fife, Orting, Pacific, Puyallup, South Prairie, Sumner, Tacoma, Wilkeson

Primary Flooding Sources: Carbon River, Carbon River, Clearwater River, Greenwater River, Mowich River, Puyallup River, South Mowich River, West Fork White River, White River

Principal Flood Problems
Major floods on the Puyallup River were recorded 18 times at the City of Puyallup between 1914 and 1943, before Mud Mountain Dam was completed. The largest flood, 57,000 cfs, occurred on December 10, 1933. The river has not exceeded zero flood damage flow (45,000 cfs at Puyallup) since the Mud Mountain Dam was completed in 1943. It is estimated that the natural peak flow of the January 1965 flood would have been 53,000 cfs, but the Mud Mountain Project reduced it to 41,500 cfs. Major flood damage still occurs in the vicinity of the Town of Orting, where the channel capacity of the Puyallup River has been exceeded frequently. The largest flood recorded at the gaging station near Orting at River Mile 26.4 was 15,300 cfs in November 1962. In December 1977, major damage occurred in the communities of Alderton and McMillin because of high flows on the Puyallup River. The only extensive flood plains on the White River are located in the Sumner area at the mouth. Mud Mountain Dam, at River Mile29.6, has regulated flood flows on the lower White River so as not to exceed 20,000 cfs and has thus limited major damage. Most of the flood damage from the Carbon River occurs in the lower4-mile reach in the vicinity of Orting. The steep gradient of the river upstream of Orting causes high velocities that erode the stream banks and result in channel changes during high flows. The channel capacity in the Orting area is estimated at 6,000 cfs. The largest flood recorded at the USGS gaging station at Fairfax (gage no. 12093900) at River Mile 17.7 was 10,000cfs in December 1977.

Lower Yakima Watershed
WA Risk MAP Rank: 7 of 67

Table 60 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Lower Yakima	2905.4	7	75.1	4	14	17	7

Communities: Benton City, Grandview, Granger, Harrah, Kennewick, Mabton, Moxee, Prosser, Richland, Sunnyside, Toppenish, Union Gap, Wapato, West Richland, Yakima, Zillah

Primary Flooding Sources
Yakima River, Ahtanum Creek, Cowiche Creek, Wide Hollow Creek

Principal Flood Problems
When the combined flow of the Naches and Yakima Rivers exceeds approximately 12,000 cubic feet per second (cfs), overflow occurs and inundates property in the floodplains. In 65 years of gage records on the Yakima River, 43 occasions of overbank flows have been observed (References 5, 6, and 7). The highest recorded flows are associated with heavy winter rainfall, sometimes augmented by rising temperatures which cause local snowmelt. Such conditions occurred in 1896, 1906, 1917, and 1933.

Peak flows observed were as follows:
November 16, 1896 45,600 cfs Union Gap
November 15, 1906 63,900 cfs Union Gap
December 30, 1917 52,900 cfs Parker
December 23, 1933 65,000 cfs Parker

After 1933, the highest winter flood flow occurred in 1974, when 28,000 cfs was recorded at Parker on January 17. Spring floods, caused by snowmelt at higher elevations in the watershed, also occur. Spring floods with flows in the range of from 12,000 to 20,000 cfs have occurred approximately 20 times during 65 years of continuous records. The three most severe spring floods recorded had peak flows as follows, measured at the Parker Gage:
June 3, 1913 22,600 cfs
June 19, 1916 24,800 cfs
May 29, 1948 37,700 cfs

The highest reported damage toll was that of the January 1974 floods, estimated at $13 million (Reference 12). The total included agricultural damage of $3 million and $4 million damage to roads, highways, and other public facilities. Seventy-seven homes were destroyed, and 383 others received major damage; 1,115 families were affected, and 2 fatalities were reported.

Snoqualmie Watershed
WA Risk MAP Rank: 8 of 67

Table 61 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Snoqualmie	694.0	18	33.6	21	15	4	8

Communities: Carnation, Duvall, North Bend, Redmond, Sammamish, Snoqualmie

Primary Flooding Sources: North Fork Snoqualmie River, North Fork Tolt River, Raging River, Snoqualmie River, South Fork Snoqualmie River, South Fork Tolt River, Tolt River

Principal Flood Problems
Climatic and topographic conditions of the upper Snoqualmie Valley, create two distinct high-flow periods each year. In the spring or early, summer, the seasonal rise in temperature melts snow in the headwaters and causes increased flow. The other high-flow period, the winter flood, is the most damaging. Winter storms bring in moisture-laden air from the Pacific Ocean and mild temperatures causing snowmelt, combined to cause floods of high magnitude and short duration. Most of the major floods have occurred during November, December, January, and February. Without the protection by flood control reservoirs, the communities along the free flowing Snoqualmie River and its forks are vulnerable to severe flooding such as occurred in November 1959 and December 1975. The largest known flood in the Snoqualmie-North Bend area occurred on November 23, 1959. As the rivers in the basin swelled on that November day, there occurred a classic example of how wildly a river can change its course. About 9 miles east of the City of North Bend, the South Fork cut a new channel on the opposite side of its valley through what was a section of the main cross state arterial, the Snoqualmie Pass Highway. The largest known flood in the Carnation area occurred in December 1975. Agriculture and transportation damages constituted the principal losses. However, the lower valley is inundated to some extent almost every winter. Other major floods occurred in February 1932, December 1967, and January 1969. Storms which cause flooding in the Tolt River Watershed are usually associated with long, steady rains (i.e., winter maritime occluded frontal systems) which are typified by longer duration, more uniform intensity, and more evenly distributed precipitation than the unstable shower (convective) storms. With this type of rainstorm, the flooding in one basin, such as the Tolt, will be associated with flooding on adjacent basins; thus, the rare occurrence of a 100-year frequency flood on the Tolt would most likely be associated with high water backwater of the Snoqualmie River. The elevation of future

floods depends upon the level of the Snoqualmie River at the peak discharge of the Tolt River, the amount of landfill or diking, the physical arrangement or layout, and the hydraulic conditions of the channel.

Grays Harbor Watershed
WA Risk MAP Rank: 9 of 67

Table 62 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Grays Harbor	587.1	29	47.2	13	23	7	9

Communities: Aberdeen, Cosmopolis, Hoquiam, Ocean Shores, Westport

Primary Flooding Sources: East Fork Humptulips River, Elk River, Humptulips River, Johns River, Little Hoquiam River, Middle Fork Hoquiam River, North Fork Johns River, South Fork Johns River, West Branch Elk River, West Fork Hoquiam River

Principal Flood Problems
Flooding in Grays Harbor County occurs principally in the winter. High spring tides and strong winds from winter storms produce storm surges that cause coastal flooding. Heavy rains with some snowmelt produce the highest runoff flows in the winter. The storms that produce the storm surges also bring heavy rains, therefore, the high riverflows are held back by tides, producing the greatest flooding at river mouths.

Duwamish Watershed
WA Risk MAP Rank: 10 of 67

Table 63 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Duwamish	495.6	12	12.7	42	5	5	10

Communities: Algona, Auburn, Black Diamond, Burien, Covington, Des Moines, Enumclaw, Federal Way, Kent, Maple Valley, Renton, SeaTac, Seattle, Tukwila

Primary Flooding Sources: Black River, Duwamish River, Green River

Principal Flood Problems
Flooding damage to crops and property in the lower Green River Valley has been a problem since the earliest settlement of the area. Flooding occurred almost annually but the impact to the farmland was minimal. After urbanization, the impact of flooding became more severe. Rapid increase in construction of roads, housing, and parking lots increased the volume and rate at which runoff reached the valley floor. Commercial and industrial landfills have been typically located in the lower valley, resulting in alteration of natural drainage patterns and reduction in overbank storage. During periods of excessive precipitation, surface and subsurface runoff from the steep valley walls cause groundwater elevations in the valley floor to rise significantly. This creates open ponding in topographically depressed areas. This condition is further aggravated by flood flows and corresponding high water

elevations on the Green River, resulting in a perched channel condition, which prevents natural drainage of subsurface water. In some areas, the overlying soils are generally less pervious than the deeper sands and runoff collects in pond perched above the water table. Under regulated conditions, significant flooding still does occur in areas unprotected by levee systems and from interior local drainage runoff that outlet to the Green River. High water levels in the Green River and concerns with existing levee system freeboard and structural integrity limit the discharge of runoff waters carried by Mill Creek (Auburn), the Black River, and various other tributaries. The high water levels of the Green River require that the tributary flows be stored and released by gravity or pump discharge to the river channel in a manner consistent with the requirements of the Green River Management Agreement. Under existing conditions, extensive backwater flooding occurs at the uncontrolled outlets of Mill Creek (Auburn) and Mullen Slough, south and west of State Routes 516 and 167, respectively.

Lake Washington Watershed
WA Risk MAP Rank: 11 of 67

Table 64 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Lake Washington	597.1	6	12.1	45	1	8	11

Communities: Beaux Arts, Bellevue, Bothell, Brier, Clyde Hill, Edmonds, Everett, Hunts Point, Issaquah, Kenmore, Kent, Kirkland, Lake Forest Park, Lynnwood, Maple Valley, Medina, Mercer Island, Mill Creek, Mountlake Terrace, Mukilteo, Newcastle, Redmond, Renton, Sammamish, Seattle, Shoreline, Tukwila, Woodinville, and Yarrow Point

Primary Flooding Sources: Cedar River, Lake Washington, Sammamish River

Principal Flood Problems
Stream flow on the Cedar River has been recorded almost continuously since 1895 at the gage near Landsburg. The greatest flood which has occurred over the past 50 years took place on December 4, 1975, with a peak discharge at Landsburg of 8,800 cfs. Based on an updated frequency curve for the Renton USGS stream gage for the 40 years of record through 1985, the recurrence interval for that event exceeded 100 years. Preliminary peak flow estimates by the USGS (Reference 22) for the recent November 1986 event indicate a peak flow of approximately 5,300 cfs, with a recurrence interval of approximately 100 years. Preliminary peak flow estimates by the USGS (Reference 22) for the recent November 1986 event indicate a peak flow of approximately 5,300 cfs, with a recurrence interval of approximately 10 years. Damages in the Cedar River basin from the December 1975 flood event were estimated at $1,760,000. In the reach under study, the west bank of an improved channel at the mouth of the Cedar River was overtopped above the South Boeing Bridge and the Renton Municipal Airport experienced significant flooding and had to close down until the floodwaters receded. Extent of flooding for the November 1986 event in the lower 2-mile reach under study was mainly limited to the improved channel with the exception of some overbank flooding adjacent to the Renton Airfield. Upstream of the improved channel, portions of the Maplewood Additions and other scattered residential developments have been inundated by past flooding events. Log and debris jams have been experienced on the lower river channel, especially during the 1933 and 1975 floods. The lower reach of the river channel, through the City of Renton, has been aggrading in recent years based on comparison of current and previous cross section data. This may result in increases in flood levels and potential overflows.

Nooksack Watershed
WA Risk MAP Rank: 12 of 67

Table 65 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Nooksack	790.1	16	49.5	11	18	19	12

Communities: Bellingham, Everson, Ferndale, Lynden

Primary Flooding Sources: Lummi River, Middle Fork Nooksack River, Nooksack River, North Fork Nooksack River, Red River, Samish River, South Fork Nooksack River

Principal Flood Problems
Large, scattered areas of the Nooksack River Valley are annually subject to local flooding. The remainder of the floodplain is subject to flooding approximately once in 2 to 5 years, affecting areas utilized almost entirely for agriculture and containing both farm and residential buildings. Maximum known flow was 49,300 cubic feet per second (cfs) at Deming in 1932 as computed from high-water marks. At this discharge, most of the floodplain is inundated. Along the South Fork and downstream near Everson, the flooded area is an irregular strip approximately 0.5 mile wide. Between the constrictions at Everson and Ferndale, the floodwater surface varies from 1 to 2 miles in width, and downstream of Ferndale, the delta is covered for a width of 3 to 4 miles. In the agricultural setting of the Nooksack Valley, the greater part of flood damage occurs to land and crops. This results from drowning of grasses and other plants; loss of livestock; erosion of banks and fallow ground; leaching of fertilizer; infestations by weed seed; carrying away of fences; deposition of sand, gravel, and driftwood; and temporary loss of pasture use because of ground saturation. A special situation occurs in the delta when tidal dikes are breached by impounding river waters. The resulting saltwater intrusion may reduce productivity for several years.

Next in order of importance are damages to buildings, particularly in the low-lying areas of populated areas and to a lesser extent on farms. Damage to levees by erosion and overtopping is a significant problem, recurring during most large floods. Floods in 1951, 1975, 1989, 1990, 1999, and 2002 caused levees to fail along both banks of the Nooksack River. Roadways suffer erosion of embankments and shoulders, undermining of pavement, and a temporary weakening because of subgrade saturation. Restriction of travel may cause financial losses. In the upper portions of the valley above Everson, flood damages consist chiefly of bank erosion and the deposition of sand and gravel on farmlands.

Stillaguamish Watershed
WA Risk MAP Rank: 13 of 67

Table 66 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Stillaguamish	702.6	21	34.5	20	21	11	13

Communities: Arlington, Granite Falls, Marysville, Stanwood

Primary Flooding Sources: Boulder River, North Fork Stillaguamish River, South Fork Stillaguamish River, Stillaguamish River

Principal Flood Problems
Streamflow records for the Stillaguamish River have been reported at USGS stream-gaging stations on the South Fork Stillaguamish River near the City of Granite Falls and North Fork Stillaguamish River near the City of Arlington since 1928. Streamflow records are not available for the main stem, but river stages are reported from a National Weather Service (NWS) non-recording gage on the Stillaguamish River at the City of Arlington. All major floods of record on the Stillaguamish River have occurred between November and February and were caused by high rates of precipitation with accompanying snowmelt. Discharges usually rise and fall rapidly, and two or more crests may occur in rapid succession as a series of storms move across the basin. The Stillaguamish River basin suffers damaging floods approximately every 3 to 5 years. From the confluence of the North and South Fork Stillaguamish Rivers at the City of Arlington, the Stillaguamish River meanders westerly 23 miles through a fertile floodplain. In the vicinity of the community of Silvana, the stream flows through two channels, Cook Slough and the Stillaguamish River. The channels recombine near River Mile (RM) 11 and then divide again near RM 8. From this point, the main stream flows approximately 2 miles through Hat Slough and discharges into Port Susan. Below the head of Hat Slough, the old Stillaguamish River channel, via the City of Stanwood, has become aggraded to the extent that it carries little or no river flow during the dry season. Below the City of Stanwood, flows in the old channel discharge into Port Susan through South Pass and into Skagit Bay through West Pass. The Stillaguamish River system is tidal for approximately 11.5 miles upstream from its mouth. The total range between mean higher-high water and mean lower-low water is approximately 11 feet.

Nisqually Watershed
WA Risk MAP Rank: 14 of 67

Table 67 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Nisqually	769.8	13	33.1	22	12	25	14

Communities: DuPont, Eatonville, Lacey, McKenna, Roy, Yelm

Primary Flooding Sources: Little Mashel River, Little Nisqually River, Mashel River, Nisqually River, Paradise River

Principal Flood Problems
Flood damage along the Nisqually River is generally limited to an area near the community of McKenna at River Mile 21.8 and to the Nisqually Delta, which is a wide 3-mile-long flood plain at the mouth of the river. The land from McKenna to LaGrande Dam has a narrow flood plain with limited access. Approximately 18,000 cfs in the Nisqually River at McKenna is considered to represent the upper limit of zero flood damage. This flow has been exceeded six times during the period of record (1947-78) at the USGS gaging station on the Nisqually River below Powell Creek near McKenna (gage no. 12088400) at River Mile 31.6. At this station, the three most severe floods occurred in December 1975 (30,700 cfs), January 1965 (25,700 cfs), and January 1974 (23,200 cfs). An estimated flood of 42,000 cfs at the same site occurred in December 1933, inundating most of the delta.

Lower Willamette Watershed
WA Risk MAP Rank: 15 of 67

Table 68 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Lower Willamette	644.1	99	26.7	28	7	27	15

Communities: Battle Ground, Camas, Ridgefield, Vancouver

Primary Flooding Sources: Columbia River

Principal Flood Problems
Although many large Columbia River floods have occurred in Clark County, existing flood control storage will reduce the severity of future floods. The June 1948 and June 1956 floods were typical spring-summer floods caused by snowmelt runoff. Although less significant than the aforementioned floods, the December 1964 flood is noteworthy because it was an unusually large winter flood resulting primarily from rainfall. Peak discharges at the U.S. Geological Survey (USGS) gage at The Dalles, Oregon, for the June 1948 and June 1956 floods were 1,010,000 and 823,000 cubic feet per second (cfs), respectively. Discharges are given for The Dalles (approximately 55 miles upstream of Vancouver) rather than at Clark County because The Dalles is the first gage upstream of the mouth of the Columbia River with a reliable stage- discharge relationship. The discharge of the December 1964 flood is not comparable to the floods of 1948 and 1956 because large inflows occurred downstream of The Dalles. The estimated return periods for the 1948 and 1956 floods were 48 years and 18 years, respectively.

The Columbia River floods of 1948 and 1956 caused light damage to residential areas of Clark County. Most of the damage in the unincorporated areas occurred in low lying farm and industrial areas. Emergency flood fighting measures along the Columbia River and temporary evacuation reduced damage.

Lower Chehalis Watershed
WA Risk MAP Rank: 16 of 67

Table 69 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Lower Chehalis	817.9	17	65.6	6	29	21	16

Communities: Aberdeen, Cosmopolis, Elma, McCleary, Montesano

Primary Flooding Sources: Canyon River, Chehalis River, East Fork Satsop River, East Fork Wishkah River, Little River, Middle Fork Satsop River, Satsop River, West Fork Satsop River ,West Fork Wishkah River, Wishkah River, Wynoochee River

Principal Flood Problems

Flooding in Grays Harbor County occurs principally in the winter. High spring tides, and strong winds from winter storms produce storm surges that cause coastal flooding. Heavy rains with some snowmelt produce the highest runoff flows in the winter. The storms that produce the storm surges also bring heavy rains, therefore, the high riverflows are held back by tides, producing the greatest flooding at river mouths. Flows have been recorded, on the Chehalis River at Porter since January 1952. The two largest floods on record at this station had discharges of 55,660 cubic feet per second (cfs) (January 1972) and 49,600 cfs (January 1971). The COE estimates the recurrence intervals for these floods are once in 75 years and once in 60 years, respectively (Reference 1). The COE completed construction of a dam on the Wynoochee River at RM 51.8 in August 1972. Until January 1982, the highest flow recorded at the gage located just above Black Creek was 18,100 cfs in December 1972. Based on the exceedance-frequency curve developed by the USGS for this gaging site, this discharge has a recurrence interval of approximately once in 2 years. There is a gage on the Satsop River at RM 2.3. This gage has been in operation since March 1929. The highest discharge recorded at the gage has been 46,600 cfs in January 1935. Based on the exceedance-frequency curve developed by the USGS for this gaging site, this discharge has a recurrence interval of approximately once in 50 years.

Lower Cowlitz Watershed
WA Risk MAP Rank: 17 of 67

Table 70 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Lower Cowlitz	1451.1	28	40.2	19	28	13	17

Communities: Castle Rock, Kelso, Longview, Morton, Mossyrock, Toledo, Vader, Winlock

Primary Flooding Sources: Coweman River, Cowlitz River, East Fork Tilton River, Green River, North Fork Tilton River, North Fork Toutle River, South Fork Toutle River, Tilton River, Toutle River, West Fork Tilton River

Principal Flood Problems
Major floods usually result from a combination of intense rainfall and snowmelt after the watershed has been saturated from prior rainfall. Columbia River floods generally are an annual event which occurs in the spring when the snow melts in the mountains. However, there has been winter flooding through the study reach of magnitudes comparable with the larger spring freshets. Flooding from rivers and smaller creeks within the Cowlitz, Kalama, and Lewis River basins generally occurs during the winter months of November through January. The historical record of flooding in Cowlitz County is available only for the period since substantial population centers became established. In December 1933, the county experienced one of the worst and most extensive floods in memory when Cowlitz, Coweman, Kalama, and Lewis Rivers Peaked well in excess of their current estimated 100-year discharge. Damage to the area was estimated at more than $3 million, occurring mainly within the populated urban centers of Kelso, Castle Rock, and Woodland when protective dikes were washed out and nearly 3000 people were forced to evacuate their homes because of the high water. Several major ridges were destroyed, and considerable damage to rural highways and farmland was incurred. In June 1948, Columbia River swelled to a peak discharge of more than 1 million cubic feet per second and caused estimated $7.2 million damage, $6 million of which was to farm property, in the region from Woodland to Willow Grove. Flooding was intensified by high tides which affected Columbia River elevations within Cowlitz County.

Lower Columbia-Clatskanie Watershed
WA Risk MAP Rank: 18 of 67

Table 71 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Lower Columbia-Clatskanie	907.0	10	25.2	29	26	16	18

Communities: Cathlamet, Kalama, Kelso, Longview, Woodland

Primary Flooding Sources: Columbia River

Principal Flood Problems
Although many large Columbia River floods have occurred in Clark County, existing flood control storage will reduce the severity of future floods. The June 1948 and June 1956 floods were typical spring-summer floods caused by snowmelt runoff. Although less significant than the aforementioned floods, the December 1964 flood is noteworthy because it was an unusually large winter flood resulting primarily from rainfall. Peak discharges at the U.S. Geological Survey (USGS) gage at The Dalles, Oregon, for the June 1948 and June 1956 floods were 1,010,000 and 823,000 cubic feet per second (cfs), respectively. Discharges are given for The Dalles (approximately 55 miles upstream of Vancouver) rather than at Clark County because The Dalles is the first gage upstream of the mouth of the Columbia River with a reliable stage- discharge relationship. The discharge of the December 1964 flood is not comparable to the floods of 1948 and 1956 because large inflows occurred downstream of The Dalles. The estimated return periods for the 1948 and 1956 floods were 48 years and 18 years, respectively.

The Columbia River floods of 1948 and 1956 caused light damage to residential areas of Clark County. Most of the damage in the unincorporated areas occurred in low lying farm and industrial areas. Emergency flood fighting measures along the Columbia River and temporary evacuation reduced damage.

Upper Yakima Watershed
WA Risk MAP Rank: 19 of 67

Table 72 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Upper Yakima	2138.8	11	44.0	15	36	18	19

Communities: Cle Elum, Ellensburg, Kittitas, Roslyn, Selah, South Cle Elum

Primary Flooding Sources: Cle Elum River, Cooper River, Kachess River, Middle Fork Teanaway River, North Fork Teanaway River, Teanaway River, West Fork Teanaway River, Yakima River

Principal Flood Problems

Floods on the Yakima, Teanaway, and Cle Elum Rivers occur as the result of snowmelt in spring and early summer, and occur after heavy rains in November and December. The snowmelt floods are characterized by slow rise and long duration of flow; river stages may be increased by ice and debris jams. The winter flood crests are reduced because of Kachess, Keechelus, and Cle Elum Lakes' reservoir storage as flooding occurs after the irrigation season when storage is available. However, these reservoirs control only a small part of the runoff, and storage may not be available if a second winter flood occurs. Since 1862, 18 floods have occurred on the Yakima River and its tributaries. Five of the most severe floods occurred in November 1906 (41,000 cubic feet per second (cfs)), December 1933 (32,200 cfs), May 1948 (27,700 cfs), December 1975 (16,600 cfs), and December 1977 (21,500 cfs). These peak discharges were recorded at the U.S. Geological Survey gaging station on the Yakima River at Umtanum, Washington, Station No. 12484500. This site is 10 miles south of Ellensburg. Ellensburg and Kittitas are surrounded by a complex irrigation system consisting of the North Branch, Town, and Cascade Canals; Whipple Wasteway; and Reecer, Currier, Whiskey, Mercer, Wilson, Cooke, and Caribou Creeks. This system has a decreasing capacity downstream, and, if used to route floodwaters, may be overtaxed. In the 1948 flood, floodwaters diverted from one basin caused problems in another. Ice and debris have an impact on flood stages when culverts and bridges are obstructed. Historic high-water elevations and streamflow information were obtained from U.S. Geological Survey publications. Other high-water marks were obtained from records of the floods of December 1975 and December 1977 by the study contractor.

Skykomish Watershed

WA Risk MAP Rank: 20 of 67

Table 73 HUC8 Name	HUC8 sq. mi.	FEMA Trifecta Rank	Floodplain sq. mi.	Floodplain Area Rank	Population Density Rank	Policies & Claims Rank	Risk Rank
Skykomish	834.8	19	22.1	33	33	10	20

Communities: Everett, Gold Bar, Index, Monroe, Skykomish, Sultan

Primary Flooding Sources: Beckler River, North Fork Skykomish River, Rapid River, Skykomish River, South Fork Skykomish River, Sultan River, Wallace River

Principal Flood Problems

Flooding of the City of Everett may occur from high tide levels in Puget Sound or from floods on the various rivers and streams in the county. High tides alone do not usually cause flooding but, when combined with high winds, can cause flooding along the coastline. Tidal flooding within the City of Everett along the coastal industrial area has occurred three times in the last 25 years, as reported by local residents. Coincidence of the annual highest tide level with a river peak can enlarge the extent of river flooding, but over the 30 years during which records have been kept, the magnitude of such coincident tides has not exceeded that having a 3-year recurrence interval. The major problem associated with floods within the City of Everett has been inundation of the low-lying agricultural lands, resulting in loss of crops and, in some cases, failure of dikes and blocked roads. Within the City of Monroe, the estimated 100-year flood from the Skykomish River will inundate approximately 80 acres of undeveloped land in the south and southeastern parts of the city. The estimated 100-year flood from the Snohomish River will inundate approximately 100 acres of developed agricultural land in the extreme northwestern part of the city. The Woods Creek floodplain in the City of Monroe is dominated by floodwaters backing up from the Skykomish River. Flooding in the City of Mukilteo may occur from high-tide levels and storm surge accompanied by winds in Possession Sound. Very little flood-damage potential exists in the City of Mukilteo area. Flooding in the City of Snohomish by the Snohomish and Pilchuck Rivers is confined primarily to the southeastern part of the City where there are scattered residences and undeveloped land. Photographs of the 1951 flood and the 1979 flood on the Snohomish River at the City of Snohomish are shown in Figures 3, 14, and 15. Flooding in the City of Sultan is caused by major floods on the Sultan and Skykomish Rivers. The Wallace River is not a major flooding factor because areas subject to flooding from the Wallace River are more significantly affected by backwater from the Skykomish River. Flooding occurs in the City of Sultan when high flows on the Sultan and Skykomish Rivers go over the banks on the western and southern sides of the city. Floodwaters also enter the City of Sultan when high flows on the Skykomish River back up into the Sultan River and go over banks on both sides of the lower Sultan River.

Glossary of Flood Terms

1.0-precent annual chance flood: The flood having a 1% or greater probability of occurring in any year; also called the 100-year flood

0.2-precent annual chance flood: The flood having a 0.2% or greater probability of occurring in any year; also called the 500-year flood.

Base Flood: A flood having a 1-percent probability of being equaled or exceeded in any given year; also referred to as the 100-year flood.

Base Flood Elevation (BFE): Defined by FEMA as the elevation of the crest of the base or 100-year flood relative to mean sea level. BFE is not depth of flooding. To determine depth of flooding, you would need to subtract the lowest elevation of a particular property from the BFE.

Flood Insurance Rate Map (FIRM): An official map of a community, on which the Federal Insurance and Mitigation Administration has delineated both the Special Flood Hazard Areas and the risk premium zones applicable to the community. Most FIRM's include detailed floodplain mapping for some or all of a community's floodplains.

Floodplain: Any land area susceptible to being inundated by floodwaters from any source.

Freeboard: A margin of safety added to the base flood elevation to account for waves, debris, miscalculations, or lack of data.

Panel: Panel number is numerical designation used to identify the FIRM Map associated with a given area. The first six digits of the Panel number is the community number.

Panel Date: This is the date recorded in the FEMA FMSIS database, which is associated with the given Panel Number.

Repetitive Loss Property: A property for which two or more National Flood Insurance Program losses of at least $1,000 each have been paid within any 10 year period since 1978.

Special Flood Hazard Area (SFHA): An area designated as within a "Special Flood Hazard Area" (or SFHA) on a FIRM. This is an area inundated by 1% annual chance flooding for which BFEs or velocity may have been determined. No distinctions are made between the different flood hazard zones that may be included within the SFHA. These may include Zones A, AE, AO, AH, A99, AR, V, or VE.

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Landslide

	Frequency	50+ yrs	10-50 yrs	1-10 yrs	Annually
	People	<1,000	1,000-10,000	10,000-50,000	50,000+
	Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
	Environment	<10%	10-15%	15%-20%	20%+
	Property	<$100M	$100M-$500M	$500M-$1B	$1B+
Landslide	**Hazard scale**		< Low to High >		

Risk Level

Frequency – Landslides happen in Washington on an annual basis.

People – The likelihood that a single landslide would kill 1,000 people to meet the minimum threshold for this category is felt to be highly unlikely.

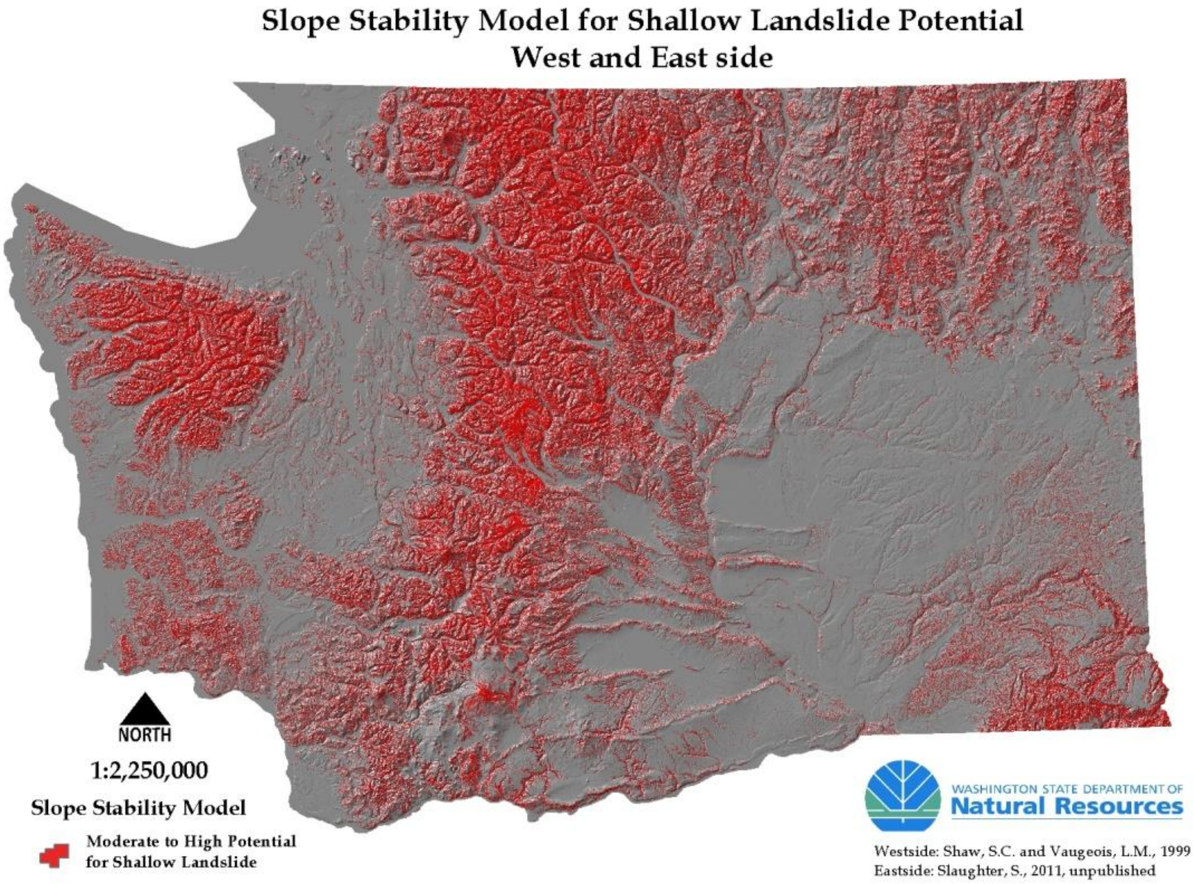
Economy – While the cost to recover from or the money it takes to mitigate a landslide is substantial, the likelihood that a landslide would cost 1% of the State's Gross Domestic Product (GDP) to meet this category's minimum threshold is highly unlikely.

Environment – While the environment and species that inhabit the areas in and around a landslide can be adversely affected in an event, the likelihood that 10% of a single species or habitat will be lost due to a landslide is highly unlikely.

Property – During the week of February 4, 1996, sustained heavy rainfall at lower elevations caused more than $300 million dollars worth of damage due to flooding and landsliding in the Puget Sound region. The January 2007 storms may have been more costly.

HIVA Risk Classification for Landslide is 4A or Mitigation to Reduce Risk is Optional.

Figure 65 Hazard Area Map



The landslide hazard map for Washington (Figure 1) was derived from the United States Geological Survey (USGS)[158] open-file report titled, Landslide Overview Map of the Conterminous United States. A GIS data file was obtained for this map from the USGS and the landslide hazards for Washington were extracted to create the map. Landslide hazard areas are colored similar to the colors used for the original U.S. map. The landslide hazard is based on either the landslide incidence or the susceptibility of a landslide to occur in a given area. Susceptibility is not indicated on the map where it is the same or lower than incidence. Susceptibility to landsliding was defined as the probable degree of response of [the areal] rocks and soils to natural or artificial cutting or loading of slopes, or to anomalous high precipitation. High, moderate, and low susceptibility are delimited by the same percentages used in classifying the incidence of landsliding.

Summary

The hazard – Landslides are the movement of rock, soil, and/or debris down a slope. Ground failures that result in landslides occur when gravity overcomes the strength of the soil and rock in a slope, often with the help of contributing factors such as heavy rainfall, erosion of the toe of a slope, ground shaking, or human action. Landslides take lives, destroy buildings, disrupt infrastructure, interrupt transportation systems, damage utilities, and cause environmental damage.

Previous occurrences – Washington has a long history of landslides. Widespread landslides have historically occurred during large storm events (1983, 1996, 1997, 2007, and 2009) and earthquakes (1949, 1965, and 2001). Landslides can also move without large events and without warning, such as the Aldercrest-Banyon landslide in Cowlitz County, the Carlyon Beach/Hunters Point landslide in Thurston County, and the Nile Landslide in Yakima County. Landslides can also be caused by volcanoes, such as the debris avalanche of the Mt. St. Helens eruption of 1980 and subsequent lahars (volcanic debris flows).

Susceptibility and probability of future events – Landslides are natural but can be exacerbated by development and will continue to occur throughout the state. Geologic mapping, landform mapping and landslide susceptibility mapping and modeling are all effective tools in determining areas of instability. Landslide precipitation forecasting is a new tool to forecast landslide initiation during large precipitation events.

Jurisdictions at greatest risk – Areas most susceptible to landslides are difficult to determine, since site specific variables can alter susceptibility. Areas typically susceptible to landslides are steep hillsides (20 degrees and greater) and convergent topography. Landforms can also be a factor in landslide susceptibility, such as areas of steep shoreline bluffs, colluvial hollows (bedrock hollows), inner gorges, meander bends, rugged topography (mountainous terrain), and areas with previous deep-seated landslide movement. Features such as alluvial fans are areas of deposition for debris flows and other landslides.

The Landslide Hazard [159] [160] [161] [162] [163] [164]

Landslide is a general term for any downslope movement of rock, unconsolidated sediment, soil, and/or organic matter under the influence of gravity. It also refers to the deposit itself. Landslides can be classified in several different ways. One method is to describe the type of movement (fall, topple, slide, spread, or flow) and the type of material involved (rock, soil, earth, or debris). The failure surface can be planar, in which case the slide is called translational, or curved, in which case it is called rotational, or a slump. Landslide can be small (a few cubic yards) or very large (cubic miles). They can range from very fast, as in free fall, to very slow, as in creep. Landslides can come to rest quickly or can continue to move for years or even centuries. Landslides can stop moving only to be later reactivated. These are called dormant slides. Eventually, a landslide deposit may permanently cease moving and undergo erosion and revegetation. This is called a relict slide. Landslides can injure or kill, destroy structures such as homes, businesses, and public buildings, interrupt infrastructure such as transportation or utilities, or impact the environment by disturbing or covering aquatic or other habitat or directly killing plants and animals.

Landslides can also into two major categories, deep-seated landslides, which fail below the rooting depth of vegetation (Figure 2) or shallow (Figure 3). This distinction is important to evaluating the potential effectiveness of mitigation measures such as vegetation management. Shallow landslides tend to respond to rainfall events over periods of days or weeks, whereas deep-seated slides respond to weather over periods of months, years, or even decades. In the Washington Geological Survey's statewide landslide database (Sarikhan and Davis, 2008), landslides are categorized into the following groups:

- block, fall or topple,
- debris flow,
- debris slide and avalanches,
- deep seated, deep-seated composite, deep-seated earthflow, deep-seated rotational, deep-seated translational
- hyperconcentrated flows
- shallow undifferentiated.

Ground failures that result in landslides occur when gravity overcomes the strength of the soil and rock in a slope. While gravity is the driving force of a landslide, contributing factors, include:

- Saturation, by rain on snow or heavy and/or prolonged rains that can saturate soils and create instability in weakened or weathered bedrock.
- Erosion by rivers, glaciers, or ocean waves that over-steepened slopes or results in removing support from the base of the slopes.
- Ground shaking caused by earthquakes that increase the driving force and weaken the supporting soils structure.
- Volcanic eruptions that produce lahars and instability on the lateral flanks of the volcano.
- Excess weight, from accumulation of rain or snow, from stockpiling of rock or ore, from waste piles, or from manmade structures that exert excessive stress on slopes.
- Human action, such as construction, logging, or road building that disturbs soils and weakens or removes the support for slopes, and/or increases runoff during prolonged, heavy precipitation events.

Landslides are most likely to occur where certain combinations of geologic materials are present: for example, groundwater percolating through porous and permeable sands and gravels and perching on underlying layers of impermeable silt and clay. At this interface, increased groundwater pore pressure can weaken and cause failure of the sand and gravels. In the Puget Lowland, this combination is common and widespread. Specifically, glacial outwash sand, locally called the Esperance Sand, overlies the fine-grained Lawton Clay, giving rise to oversteepened bluffs with benches composed of the perching layer (Figure 4). Similar conditions exist in many bluffs of the greater Puget Sound area (also known as the Salish Sea).

Landslides commonly occur on slopes and in areas where they have taken place before. Historically, most areas of Washington State have experienced landslides. Areas that have been most active in the recent past includes the Columbia River Gorge, the banks of Lake Roosevelt, the Prosser to Benton City section of Interstate 82, several stretches of the Interstate 5 corridor, the U.S. 101 Highway corridor along the Pacific Coast from Astoria, Oregon to Olympia, in the Cascades, Olympics, and Blue Mountains, and Puget Sound coastal bluffs.

The Washington State Department of Ecology description below illustrates three different settings of landslides that are of concern in the Puget Sound and coastal regions of Washington State.

Figure 2 shows a deep-seated landslide. This type of slide can be ancient and may persist for several millennia. These slides can reactivate every few years to decades in response to particularly wet conditions. Typically, these large slides range in area from less than an acre to several that extend over a mile of shoreline. The large ones often consist of several smaller blocks that may move independently.[165] The deep-seated slide in figure 2is rotational, that is it rotates the earth and rock backward as gravity pulls the mass of the slide downward. This type of landslide has been seen all over Washington, with a recent occurrence in 1999 at Carlyon Beach near the city of Olympia, which forced over thirty families from their homes.

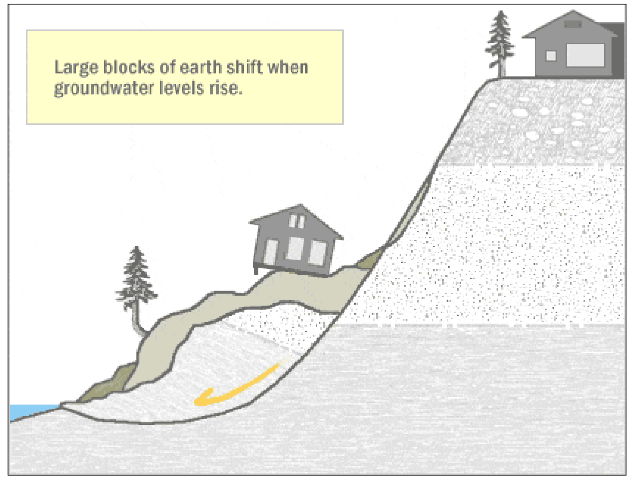


Figure 66 Deep-seated Landslide

Figure 3 shows a shallow slide. These slides are frequent and widespread along Puget Sound shoreline, typically occurring during prolonged periods of heavy rainfall. They involve a relatively thin layer (commonly less than five feet) of wet soil and vegetation, but can be dangerous, as mud and debris can travel fast and with destructive force. These slides are usually small and rarely result in serious widespread damage, although large storms can trigger hundreds or even thousands of shallow landslides, usually debris flows. The greatest danger from this type of slide is to homes or structures built close to the toe of the slope, where they may be struck or buried by rapidly moving mud and debris.

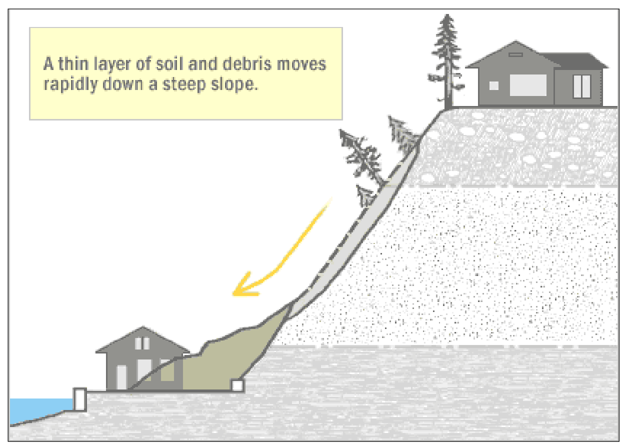


Figure 67 Shallow Landslide

Figure 4 shows a bench formation, in which permeable sediments, typically sand, overlie impermeable sediments, leading to weakening and failure of the sand. Benches may occur along layers of resistant geologic materials, where long term erosion or land sliding of the overlying units has produced a stepped slope. Benches present an attractive site for development, since they offer level ground near the water on otherwise steep terrain. In many places, roads have been built down the steep upper slope to serve home sites along the bench itself. Examples of benches can be seen along the shoreline north of Kingston, above the railroad grade north of Carkeek Park in Seattle and on Magnolia Bluff in Seattle.

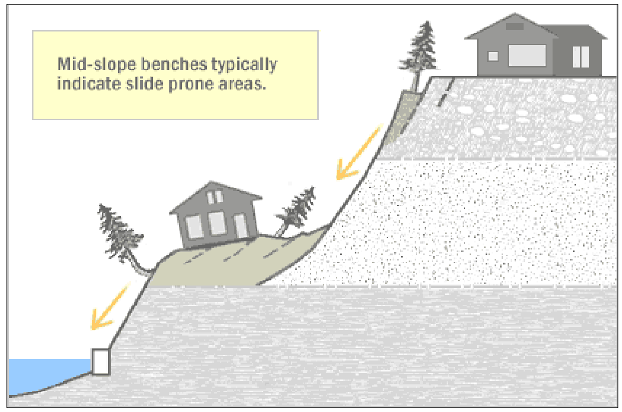


Figure 68 Bench Landslide

Figure 5 shows a large-scale landslide which are relatively rare but do periodically strike the Puget Sound's shoreline, as the large landslide that destroyed 36 homes at Carlyon Beach in Thurston County. As with any geologic hazard, small events are more common than large ones.

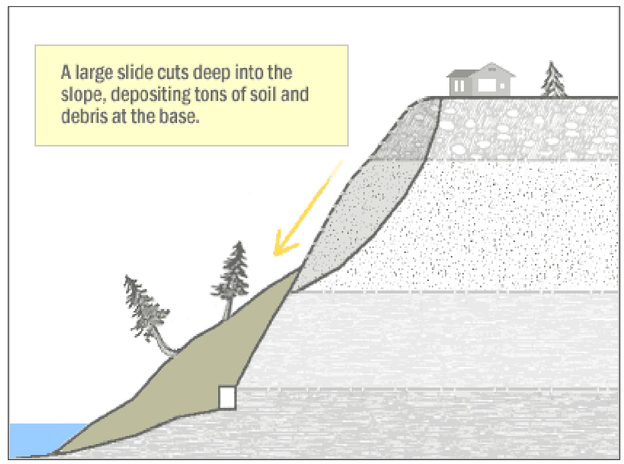


Figure 69 Large Scale Landslide

Determining probability of future landslide events in specific locations is difficult because so many factors can contribute to the cause of a landslide or ground failure. A collaboration of scientists led by the Department of Natural Resources (DNR), Division of Geology and Earth Resources continue to test a pilot system that warns of increased risk of landslides in Washington State during prolonged, heavy rainfall events. This system will be integrated into the NOAA weather alert system.

Additionally, the Washington Geological Survey hosts the Statewide Landslide database, accessible and downloadable (in GIS format) from an interactive ArcIMS site. In 2012, the Washington Geological Survey began a Puget Sound coastal bluffs mapping project using Light Detection and Ranging (LIDAR) imagery, Google Earth, aerial photography, county assessor data, landslide reports and DNR field observations to map all landslides in this area and add it to the Statewide Landslide database on the ArcIMS site. The site is available to the public, professionals, and local jurisdictions to inform them of their hazard mitigation and community planning efforts. Upon its conclusion in 2013, this landslide theme will provide consistently mapped landslides in the coastal zone of the Salish Sea.

Landslide Provinces [166]

Washington State has six landslide provinces, each with its own characteristics.

Puget Lowland – North Cascade Foothills

This landslide province is the portion of the Puget Lowland overridden by ice during the last continental glaciation. It has abundant rain, or in the foothills, rain and snow. This province has the largest and fastest growing population in the state.

Unconsolidated glacial soil material lies on top of bedrock in the lowland, sculpted and compacted by the last continental ice sheet. During the retreat of the continental glaciers to the north, extensive glacial melt water eroded deep channels in the unconsolidated glacial sediments, resulting in oversteepened, unsupported slopes like those in Hood Canal, the Tacoma Narrows, and Lake Sammamish. The channels left by the earlier glacial runoff combined with the precipitation runoff in typical northwest maritime climate and Puget Sound wave action has cut hundreds of miles of steep bluffs into the thick, unconsolidated glacial sediments. Many bluffs are in or near population centers; demand for residential development is great on these bluffs because of the economic value of views from the top or access to the beach below. Slope stability maps of the Coastal Zone Atlas (Washington Department of Ecology, 1978-1980) show more than 660 miles of bluffs as unstable.

Four landslide types affect these bluffs:

Slump – This type of landslide occurs when groundwater concentrates on layers of compact silt or clay in the lower bluff area; the existence of a saturated zone can cause the sands and gravels in the upper bluff to subside. Slumps tend to leave a distinctive mid-bluff bench; examples are found in the Alki, Fort Lawton, and Golden Gardens areas of Seattle, Scatchet Head on Whidbey Island, and the Thorndyke Bay area of Jefferson County.

Debris flows – Excessive groundwater combined with focused surface runoff during a heavy precipitation event can turn a landslide into a debris flow which occurs rapidly and typically accelerates with down slope movement. These types of landslides are usually responsible for a majority of the lives lost to landslides around the world annually. Debris flows typically contain trees and large woody debris suspended in a wet, concrete-like soil mixture that can cause loss of, or significant damage to, structures and property. Debris flows that reach a high enough speed can create a localized tsunami wave.

Dormant to relict deep-seated landslides in unconsolidated materials – Dormant and relict deep-seated landslides in the thick glacial sediments of the Puget Sound lowlands are a concern because of their large size, the difficulties the average citizen has in recognizing them, and development pressure, especially in shoreline areas. Reactivation of such landslides generally occur slowly, consisting of a few feet of movement in a particular episode, usually in the late-winter or early spring after an unusually wet or series of wet winters. Even a small amount of movement can cause severe damage to structures and utilities.

Submarine landslides – Submarine landslides typically occur on submarine deltas (common in Hood Canal) and along steep submarine bluffs, typically formed by glacial processes. These landslides are apt to go unnoticed unless they trigger noticeable water waves or damage submarine utilities. They have the potential to generate localized tsunamis in Puget Sound.

The Northern Cascade foothills are susceptible to landslides in bedrock. The foothills are subject to moist Pacific storms; the shape and contour of the foothills enhance the amount and intensity of precipitation. Recent studies following the January 7-9th, 2009 storm suggests shallow landslides predominantly occur on the Chuckanut Formation. Deep-seated landslides appear to be more common in the phyllitic rocks, such as the Darrington Phyllite.

Debris flows – These slides commonly enter confined, steeply inclined, flood-swollen stream valleys, becoming more mobile than that of an isolated coastal bluff debris flow, capable of traveling miles from their point of origin. These predominantly deposit on alluvial plains at the base of the hills.

Bedrock landslides – These landslides are in folded and faulted sedimentary and phyllitic rocks that outcrop along the edges of the northern lowland. Nearly all are dormant to relict deep-seated landslides that move by two predominant factors: by removal of support by retreating glacial ice, glacial melt-water erosion oversteepening the valley slopes, or by strong ground shaking during earthquakes.

Southwest Washington

The primary characteristics of this landslide province are the lack of glaciation and localized exposure to glacial melt water. In places, weathering processes have exposed much of the surface in this province for millions of years. Much of the province has deeply dissected terrain, with areas of midslope benches and gentle slopes at the toe of mountain slopes. Recent studies following the December 3, 2007 storm indicate that Crescent and related intrusive rocks are the dominant lithology where shallow (debris flows and debris avalanches) occur. The deep-seated landslides (earthflows and other deep-seated) occur predominantly in the surrounding marine and nearshore sediments.

Earthflow – This is the dominant form of deep-seated landslide in the province. Relict, dormant, and active earth flows are common, not only in the higher steep terrain, but also in the lower rolling hills of the Chehalis-Centralia area. Stream erosion along the toes of the earth flows usually causes reactivation of these landslides. Excavations, such as those for freeway construction, also may reactivate dormant earth flows or initiate new ones.

Dormant to relict deep-seated landslides in the Willapa Hills – Dormant to relict deep-seated landslides in the Willapa Hills of southwest Washington are a concern because of their large size and impact on commerce and utility corridors for the rural coastal communities in this part of the State. These deep-seated landslides typically occur along the deeply weathered soil interface with the bedrock. Reactivation of such landslides generally occurs slowly, consisting of a few feet of movement in a particular episode, usually in the late-winter or early spring after an unusually wet winter or during intense precipitation events. Even a small amount of movement can cause severe damage to structures and utilities. It is likely that a number of the large dormant to relict landslides in the Willapa Hills failed during strong ground shaking in this area.

Debris flows and Debris Avalanches – These types of landslides are a widespread problem in the Willapa Hills and foothills to the western Cascade Mountains; they tend to occur where the rocks have steep slopes and smooth surfaces overlain by thin soils. Debris avalanches can cause a rapid movement of material down the hill, blocking rivers and streams and creating temporary debris dams. Both debris avalanches and debris flows can deposit a tremendous amount of debris into the fluvial systems, creating large debris dams behind bridges and natural constrictions. Intense rainstorms, or rain on snow events in the mountains trigger these rapidly occurring landslides.

Cascade Range

This landslide province has a number of different landslide types because of its volcanic and alpine glacial history and climate. There are three sub-provinces in the Cascades – north of Snoqualmie Pass, south of the pass, and the strato-volcanoes, which have distinct slope stability characteristics.

The Cascades north of Snoqualmie Pass are steep and rugged, generally composed of old, strong granitic or metamorphic bedrock. The valley walls typically produce small to very large rock falls. Large deep-seated landslides, from relict to active, dot the landscape. Debris flows and to a lesser extent debris avalanches are common during prolonged, intense rainstorms and during rain on snow events. Some of these landslides have probably been triggered by strong seismic shaking.

South of Snoqualmie Pass, the peaks are primarily composed of younger volcanic sediments and rock; deep-seated landslides, earthflows, and block slides in bedrock are common throughout the area. Debris flows and to a lesser extent debris avalanches are common during prolonged, intense rainstorms and during rain on snow events. Large deep-seated landslides in volcanic sediments and bedrock occur in the Columbia River gorge area of the southern Cascades; more than 50 square miles of landslides are in the gorge, but less than 10 percent of the area is active.

The states five strato-volcanoes – Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens and Mount Adams – have layers of strong volcanic rock and weak volcanic rock lying parallel to the slopes. These volcanic deposits are prone to failure, with the weaker rock layers on the upper slopes weakened by hydrothermal action. Small rock falls and rock avalanches are common localized hazards on the slopes of the volcanoes; but earthquakes have triggered large rock avalanches. These volcanoes can also produce long distance and widespread lahars (also known as volcanic debris flows), which potentially can occur without an eruptive activity.

Okanogan Highlands

This landslide province extends from the slopes of the North Cascades in the west to the foothills of the Selkirk Mountains in the northeast corner of the state. The primary slope stability problem is sediments deposited by repeated damming of the Columbia River by lobes of the continental glacier ice sheet and repeated catastrophic floods from breached ice dams in western Montana.

Debris flows can be a hazard in this area during intense thunderstorms, usually moving through the area during late spring to late summer. The debris flows are generally sparse and due to a sparse population, damage is usually minimal. Deep-seated landslides are most common in the areas surrounding Lake Roosevelt. Deep-seated landslide movement usually occurs in areas where relict to dormant deep-seated landslides exist. Landslide activity was greater when the lake levels were rapidly drawn down for flood control and power generation, but since this type of activity has been largely discontinued, landslides rarely occur from it. Some landslide complexes extend for thousands of feet along the lakeshores, have distinct landslide headscarps in terraces 300 feet or more above reservoir level, and extend well below the surface of the water. One hazard in this setting is water waves (inland tsunamis) generated by very large and fast-moving (debris avalanche type) landslides.

Columbia Basin

This province is largely composed of thick sequences of lava flows known as the Columbia River Basalts. These lava flows can be traced from the Oregon, Washington, and Idaho border, where they were erupted from fissures in the ground, to the Pacific Ocean along the northern Oregon and southern Washington coasts via ancestral channels of the Columbia River. Sediments, sometimes thick sections, can be found between these voluminous lava flows in the Columbia Basin. These sediments are generally thicker in the western part of the province.

Between 15,000 and 12,000 years ago, the catastrophic floods originating from Glacial Lake Missoula scoured much of the Columbia Basin from the Spokane Valley to Wallula Gap near Walla Walla before following the Columbia River Gorge to the Pacific Ocean. These catastrophic flood events, as many as

104 separate floods have been documented, scoured the soils and a portion of the bedrock in much of the Columbia Basin before re-depositing it in watersheds along the edges of the main flood way. The catastrophic floods deposited the eroded rock and soil materials in the edge basins, like the Walla Walla River watershed. This left behind a history of the flood events and a soil deposit highly susceptible to erosion capped by wind-blown sands, silts, and clays known as loess. The loess deposits are extensive in the southeastern portion of the Columbia Basin.

Landslides in this province include slope failures in bedrock along the soil interbeds and in the overlying catastrophic flood sediments and loess deposits. Bedrock slope failures are most common in the form of very large deep-seated translational landslides, deep-seated slumps, or earth flows; a triggering mechanism appears to be over-steepening of a slope or removal of the toe of a slope by streams or the catastrophic glacial floods. These landslides usually move along sediment interbeds within the Columbia River Basalts. Major landslide problems occurred during the relocation of transportation routes required by the filling of the reservoir behind the John Day Dam and in the highly erosive and weak loessal soils of southeastern Washington. Rockfall occurs in the oversteepened rock slopes left behind by the erosion of the catastrophic floods along SR 730 and 14.

Irrigation in the Columbia Basin compounds the provinces landslide problems. For example, irrigation near Pasco has increased drainage and landslide problems ten-fold since 1957. Reactivations of relict and dormant deep-seated landslide complexes have occurred in the bluffs along the Columbia River upstream of Richland.

Olympic Mountains

The Olympic Mountains consist of a core of sedimentary rock that has been thrust beneath seafloor basalts, causing uplift of the mountains that continues today. Continental glacial deposits overlay much of the bedrock at lower elevations in the Olympic Mountain province. At higher elevations, the larger drainages were occupied by alpine glaciers. The headwaters of the smaller drainages, however, did not accumulate enough snow to form glaciers. The lower valleys that did not have glaciers have thick sections of weathered soil and bedrock comparable to those in the Southwest Washington landslide province. In these areas, rapid debris flows in steep channels and deep-seated slumps or earth flows are prominent. Adjacent valleys that did have glaciers have soils comparable in age, texture, physical properties, and behavior to the sediments in the Puget Lowland.

Recently glaciated valleys that head in the core rocks have landslide problems similar to those in the North Cascades. Debris flows are common throughout the Olympics during intense, prolonged precipitation events and during rain on snow events. Rockfall is also prevalent along the glacially oversteepened bedrock slopes of Lake Crescent on SR 101. Slopes composed of older sediments undercut by wave action along the Strait of Juan de Fuca experience extensive deep-seated slumps and earth flows or translational block slides similar to failures discussed in the southern Cascades.

Previous Occurrences

Landslides in the United States cause approximately $3.5 billion (year 2001 dollars) in damage, and kill between 25 and 50 people annually. Rock falls, rockslides, and debris flow primarily cause casualties in the United States. Worldwide, landslides occur and cause thousands of casualties and billions in monetary losses annually.[167]

Washington is prone to landslides due to its unique geology, with over 660 miles of pristine waterfront and the geological makeup of its soil. Most landslides in Washington occur after intense periods of rainfall on already saturated soils. One of these events occurred in the winter of 1996 (February) in which an excess of 29 inches of rain fell in the Puget Sound lowlands over a period of 3 to 4 days resulting in widespread landslides and flooding causing more than $300 million dollars (1996 dollars) in damages. Large amounts of snow fell in the Puget Sound in December 1996, followed by rapid melting of snow from the large amounts of rain that followed. The rapidly melting snow and rain caused widespread flooding and landslide in January and mid-March 1997, as additional rain triggered more landslides.[168]

Figure 70 Rolling Bay, Bainbridge Island Landslide, 1997

One widely publicized landslide from the 1997 event resulted in the deaths of four family members when a shallow debris flow landslide on Bainbridge Island, completely consumed and destroyed their home (Figure 70).

Significant Historic Landslides [169, 170, 171, 172, 173, 174, 175, 176, 177, 178]

Landslides occur throughout Washington State every year, but only a portion of landslides have been mapped or recorded. Most landslides reflect mostly urban areas because they are more readily documented.

>20,000BC (est.) – The Malaga (Stemilt) Landslide is the largest landslide complex in Washington State and one of the largest landslides in the world. It is located south of Wenatchee at the town of Malaga. Movement was probably caused by weak sedimentary rock interbedded with Columbia River Basalt. The landslide size is approximately 46 square miles in area, twice the size of the debris avalanche from the 1980 eruption of Mt. St. Helens.

400-600BC (est.) – The Church Mountain landslide occurred along the North Fork of the Nooksack River. It is considered a sturzstrom, a fast moving rock avalanche of very large size. It was probably triggered by an earthquake.

900AD (est.) – A Seattle fault earthquake occurred around this time, spawning landslides throughout Washington State. Landslides from this event blocked streams and rivers, some becoming permanent. Buried wood in these lakes helped date landslides to this event. Most notably is the Alderwood Landslide near Lynch Cove, which could have triggered a tsunami in Hood Canal. Landslides from Mercer Island into Lake Washington and a landslide at Greenwood Point into Lake Sammamish also date to this time.

1550 – 1700 (est.) – The Bonneville Landslide, a landslide inside the Cascade Landslide Complex, is in the Columbia River Gorge 30 miles east of Vancouver. Dating from a tree found in the debris suggests this landslide could have been seismically triggered from the 1700 Cascadia Earthquake. The landslide from Table Mountain shoved the river a mile off course and created a lake that may have stretched east for 100 miles. It is the youngest and largest of three landslides that make up the 14-square mile Cascade Landslide Complex north of the Columbia River near Cascade Locks and Stevenson. Explorers Lewis and Clark documented the landslide and its effects in 1803.

1700AD (est.) – A Cascadia subduction zone earthquake was the last major subduction earthquake off the Washington's coastline. Numerous landslides were triggered from this earthquake. Slide Lake and Day Lake in Skagit County have been dated through a submerged forest to probably correlate to this event.

Early 1800s – Historical accounts among the Snohomish people describe a large landslide at Camano Head that sent a tsunami south toward Hat Island. According to tribal accounts, the landslide sounded like thunder, buried a small village, and created a large volume of dust. The accounts make no mention of ground shaking, suggesting that the slide was not associated with a large earthquake. Camano Head is at the south end of Camano Island in Puget Sound.

1872 – A landslide, triggered by a 6.8 (est.) magnitude earthquake, reportedly blocked the flow of the Columbia River north of Wenatchee for several days (although some scientists dispute this). The landslide was a translational deep-seated landslide and one of many landslides to move during the earthquake. Many more landslides are noted around Lake Chelan from this earthquake.

1894 – A submarine landslide in the delta of the Puyallup River in Commencement Bay, Tacoma, caused a tsunami. These events carried away a railroad track and roadway, resulting in two deaths.

1896, 1897, and 1902 – Rain on snow events in the Cascades produced numerous landslides throughout the region. Mining operations and railroads reported landslides in transportation routes or in areas of operation.

1944 to 1953 and 2009– Massive landslides generated a number of inland tsunamis in Lake Roosevelt in Eastern Washington:

1949 – On April 13th, a magnitude 7.1 earthquake initiated in the Puget Sound Region. Landslides generated by the earthquake were reported predominantly in the Cascade Range, Puget Lowlands, and the western Columbia River Valley. In urban areas, landslides in the form of slumps, slides, and flows, occurred in areas of fill, such as roads and roadways, and areas unstable by undercutting, such as along coastal bluffs and along banks of rivers and lakes. Landslides, such as rock falls, rock slides, and rock avalanches were concentrated in the Cascade Range and Columbia River Valley. A landslide at Salmon Beach occurred three days after the April 16 magnitude 7.1 earthquake generated a tsunami in the Narrows of Puget Sound near Tacoma. According to local newspaper reports, an 11 million cubic yard landslide occurred when a 400-foot high cliff gave away and slid into Puget Sound. The slide narrowly missed a row of waterfront homes, but the tsunami damaged them.

1965 – Ground shaking produced by the April 29th Seattle-Tacoma magnitude 6.5 earthquake generated at least 21 landslides within about 60 miles of the epicenter.

1965 – A landslide-triggered tsunami overran Puget Island in the Columbia River near Cathlamet. The landslide originated from Bradwood Point on the Oregon side of the river. The wave killed one person.

May 18, 1980 - Mt. St. Helens Eruption

A 5.1 magnitude earthquake near Mount St. Helens on May 18th triggered the largest modern debris avalanche – an estimated 3.7 billion cubic yards, or 0.67 cubic miles – in recorded history. The earthquake dislodged the summit and bulging north face of the volcano, depressurizing the volcano's magma system, triggering powerful explosions and a massive eruption. Lahars (volcanic debris flows) flowed down the Toutle River, converging with the Cowlitz River and ending in the Columbia River. Lahars also were reported in Swift Creek, Pine Creek, and Muddy River drainages.

February 1996 – Storms and Landslides[179, 180]

Near-record snowfall in January followed by warm, heavy rain, mild temperatures and snowmelt in February caused a classic rain-on-snow event, triggering massive flooding and landslides throughout the state. The storm caused three deaths, and 10 people were injured. Landslides damaged or destroyed nearly 8,000 homes, and closed traffic along major highways for several days. Damage from all causes throughout the Pacific Northwest was at least $800 million. Stafford Act disaster assistance provided was $113 million. Small Business Administration disaster loans approved was $61.2 million.

The landslide that created the most significant impact blocked Interstate 5 and the state's main north-south railroad tracks three miles north of Woodland, Cowlitz County. The initial slide on February 8th blocked northbound lanes of I-5; a second, larger slide covered all lanes of the freeway as well as the railroad tracks to the west. It took crews until February 19th to fully reopen the interstate.

The highest concentration of landslides occurred at the northwest edge of the Blue Mountains near Walla Walla. The main areas affected were the Mill Creek, Blue Creek, Touchet, Tucannon, and Walla Walla drainages. Debris flows were most numerous on open, grassy hillsides. In the Mill Creek area, debris flows destroyed seven vehicles and five homes. Similar occurrences of flooding and landslides took place in 1931 and 1964.

December 1996 – January 1997 Holiday Storms and Landslides [181, 182, 183]

Snowmelt and rainfall in late December 1996 and January 1997 triggered hundreds of landslides and debris flows in the steep bluffs and ravines that border Puget Sound, Lake Washington, and the larger river valleys between late December 1996 and mid March 1997. Landslides caused the deaths of at least four people, millions of dollars of damage to public and private property, lost revenues, traffic diversions, and other losses.

December precipitation was 191 percent of normal. More than 130 landslides occurred between Seattle and Everett, primarily along shorelines. Although shallow slides and debris flows were the most common slope failures, many deep-seated slides also occurred. Many bluffs and steep hillsides were sites of recurring failures. Washington State was declared Federal Disaster #1159. Stafford Act disaster assistance provided was $83 million. Small Business Administration loans approved was $31.7 million. Most landslides that resulted from these storms occurred mainly in and north of Seattle – along the bluffs of Puget Sound, Lake Washington, Lake Union, Portage Bay, West Seattle, Magnolia Bluff, and along the I-5 corridor. Many smaller landslides were scattered west and south of Seattle in Kitsap and Pierce counties.

October 1998 – Aldercrest Landslide Disaster [184, 185]

The Aldercrest Landslide Disaster is the second-worst landslide disaster in United States history. Of the 137 homes in the east Kelso, Cowlitz County, neighborhood, the landslide destroyed or badly damaged 126 homes; a demolition contractor eventually removed the damaged structures. Washington State was declared Federal Disaster #1255. Stafford Act disaster assistance provided was $12.1 million. Small Business Administration disaster loans approved was $38.7 million. This ancient landslide began moving in March 1998 after soils were saturated by three straight years of above average rainfall. Eleven homeowners remained on a bluff above the slide; geologists say their houses eventually will succumb to the slide.

February 28, 2001 - Nisqually Earthquake [186]

The earthquake, magnitude 6.8, struck the Puget Sound area at 10:54 a.m. It produced a number of significant, but widely scattered landslides that caused damage resulting in direct monetary losses of $34.3 million; indirect costs such as loss of productivity, revenues and tax receipts, reduced real estate values, injuries, and environmental impacts are not included. Washington State was declared Federal Disaster #1361. Stafford Act disaster assistance provided was $155.9 million. Small Business Administration disaster loans approved was $84.3 million. Federal Highway Administration emergency relief provided was $93.8 million.

October 2003 – Floods and Storms

Heavy rainfall caused severe flooding and landslides in 15 counties. Landslides or ground failures caused temporary closures on nine state highways. Among the most significant events were a series of mud and rockslides that closed State Route 20 between Skagit and Okanogan Counties, and a landslide on State Route 112 in Clallam County that isolated the Makah Indian Reservation near the Sail River. Other landslide-related transportation problems included debris over the roadway or lodged beneath bridges on U.S. Highway 101 in Jefferson and Mason Counties, U.S. Highway 2 in Snohomish County, and State Route 410 in Pierce County. Washington State was declared Federal Disaster #1499. Stafford Act disaster assistance provided was $ 5.8 million. Small Business Administration disaster loans approved was $ 2.1 million.

The most significant landslide was a series of rockslides that closed State Route 20, the North Cascades Highway. The largest, estimated at two to three million cubic yards, demolished the highway and isolated the town of Diablo. People and supplies were shuttled in and out of the town via helicopter for a month during the winter. The highway reopened April 8, 2004 for the season (the highway closes during the winter due to the threat of snow avalanche). Electronic monitoring devices connected to warning signs were installed to detect rock movement and to warn drivers if a rockfall occurs or is imminent.

August 2004- Thunderstorms [187, 188, 189]

An intense thunderstorm on August 16-17 triggered four landslides near Rainy Pass, stranding 40 motorists and 25 firefighters. The landslides occurred on the North Cascades Highway at mileposts 149, 150, 153, and 156. Heavy rains also caused a wash out (by a debris flow or hyperconcentrated flow) on a USFS road leading to Harts Pass.

2005 Slides Close Interstate 90 at Snoqualmie Pass [190]

A large rockslide in the early hours of Sept 11th collapsed onto a car, killing the three women inside. The landslide closed two westbound lanes and produced up to 30 dump truck loads (~300 cubic feet) of rock to clear. The landslide occurred several miles west of Hyak. A smaller rockslide also occurred on Sept 12th a few miles west of Snoqualmie Pass, causing no fatalities and closed two westbound lanes. A large rockslide just east of Snoqualmie Pass closed I-90 on November 6th, but reopened two lanes late November 7th. The landslide restricted and slowed traffic through the area for about two weeks near the Thanksgiving holiday weekend. Motorists were advised to take alternate routes through the Cascade Mountains, and the State Patrol used traffic control measures to limit and slow traffic through the slide area. The landslide was stabilized by removal of loose material and by the installation of a mesh fence to prevent additional rock fall from entering the roadway. Workers removed about 100 dump truck loads (~1,000 cubic feet) of debris from the site.

2006 Storms and Landslides [191]

Prolonged rainfall from December 2005 into January 2006 caused numerous landslides throughout the state. Records of landslides are best documented in King County, but other counties also had numerous landslides move. Slides, slumps, or settlement closed lanes of Interstate 5, U.S. 101, SR 4, SR 9, SR 14, SR 107, SR 105, SR 112, SR 116, SR 166, SR 302, and SR 530 for various periods. Governor Christine Gregoire declared a state of emergency following unprecedented 13 inches of rain in 26 days and $7.3 million in damage to infrastructure (primarily transportation) in Clallam, Grays Harbor, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Pierce, Skagit, Spokane and Thurston counties. After more winter storms, Governor Christine Gregoire signed an Emergency Proclamation on February 3rd requesting federal funds for all 39 counties.

A Pineapple Express packed with wind and heavy rain moved into Western Washington on November 6th, bringing flooding and landslides. Governor Christine Gregoire declared a state of emergency for 18 counties. A landslide occurred near Lake Crescent, blocking one lane. In Pend Oreille County, a large rockfall closed Highway 395, hitting a truck and a car. The occupants escaped unharmed. King County had a small amount of landslides across the area; one near Raging River destroyed the access to Upper Preston and temporarily isolating 200 homes. State Route 508, on the east side of Bear Canyon, failed and the road was closed for several months while repairs were made to the highway. The upper Cowlitz

River valley was particularly hard-hit with numerous slides and debris flows that destroyed houses and seriously impacted state and local transportation infrastructure.

Figure 71. At about 9 p.m. on Saturday, May 13, 2006, a large section of bluff sloughed off and covered about a quarter-mile of Road 170 to a depth of about 40 feet. Photo courtesy of the South Columbia Basin Irrigation District.

The Hanukkah Eve Wind Storm of 2006 brought hurricane force wind gusts and heavy rains to Western Washington between December 14th and December 15th. The storm brought with it a small amount of landslides reported around Western Washington, but was overshadowed by the enormous wind damage and the resulting 1.8 million residences and businesses without power. Seattle reported five landslides across the city. The end of December brought more landslides to the Puget Sound coastal bluffs. A landslide just north of Carkeek Park in Seattle covered railroad tracks 20 feet wide and about a foot deep on December 26th. The landslide stopped passenger rail service for a mandated 48 hours.

December 2007 Floods

The storm event of December 1–3, 2007, was a truly historic event, where snow, strong winds, and heavy rainfall battered western Washington, triggering thousands of landslides and causing major flooding on numerous rivers. The storm came in three parts, bringing winds and heavy snow on December 1st. Warm temperatures and heavy rain followed on December 2-3, rapidly melting snow. Hurricane force winds blew into the area on December 3rd, hugging along the coastline with sustained winds of 80 miles per hour and gusts up to 145 miles per hour. It created a massive blowdown zone of timber, 600 to 800 million board feet, along the coastline.

Figure 72. Landslide at Rock Creek north of Skamania; taken on November 16, 2007.

Landslides blocked or damaged roads, isolating communities in the height of the storm and delaying emergency response. At least one person died as a consequence of the storm. The precipitation was mostly concentrated on the western side of Puget Sound and created a band of landslides from Mason County to Jefferson County. Just west of Pe Ell (Lewis County), a massive debris avalanche along with numerous smaller landslides blocked State Route 6, from Pe Ell to Raymond, isolating 21 households without electricity and water. In addition, State Route 8, just west of the SR 101 interchange in the vicinity of MP 18, State Route 12 in the vicinity of MP 27 between Porter and Malone, and SR 508 near Onalaska were blocked by landslides.

In the Chehalis headwaters area, the hardest hit area from the storm, nearly 20 inches of rain was recorded within a 48-hour period, most of that falling within the first 24 hours. Intense flooding followed the heavy rain, primarily along the Chehalis River occurred. Woody debris and sediment, including material from more than 1,000 landslides in the Chehalis headwaters basin, clogged channels at bridges, creating temporary dams and causing widespread deposition of logs and debris, especially across the Boistfort valley. The flood waters reached Chehalis and Centralia on December 3rd, inundating Interstate 5 with as much as 10 feet of water and flooding numerous homes. The flood waters persisted and kept I-5 closed until December 6th, when flood waters finally receded enough to reopen the interstate highway.

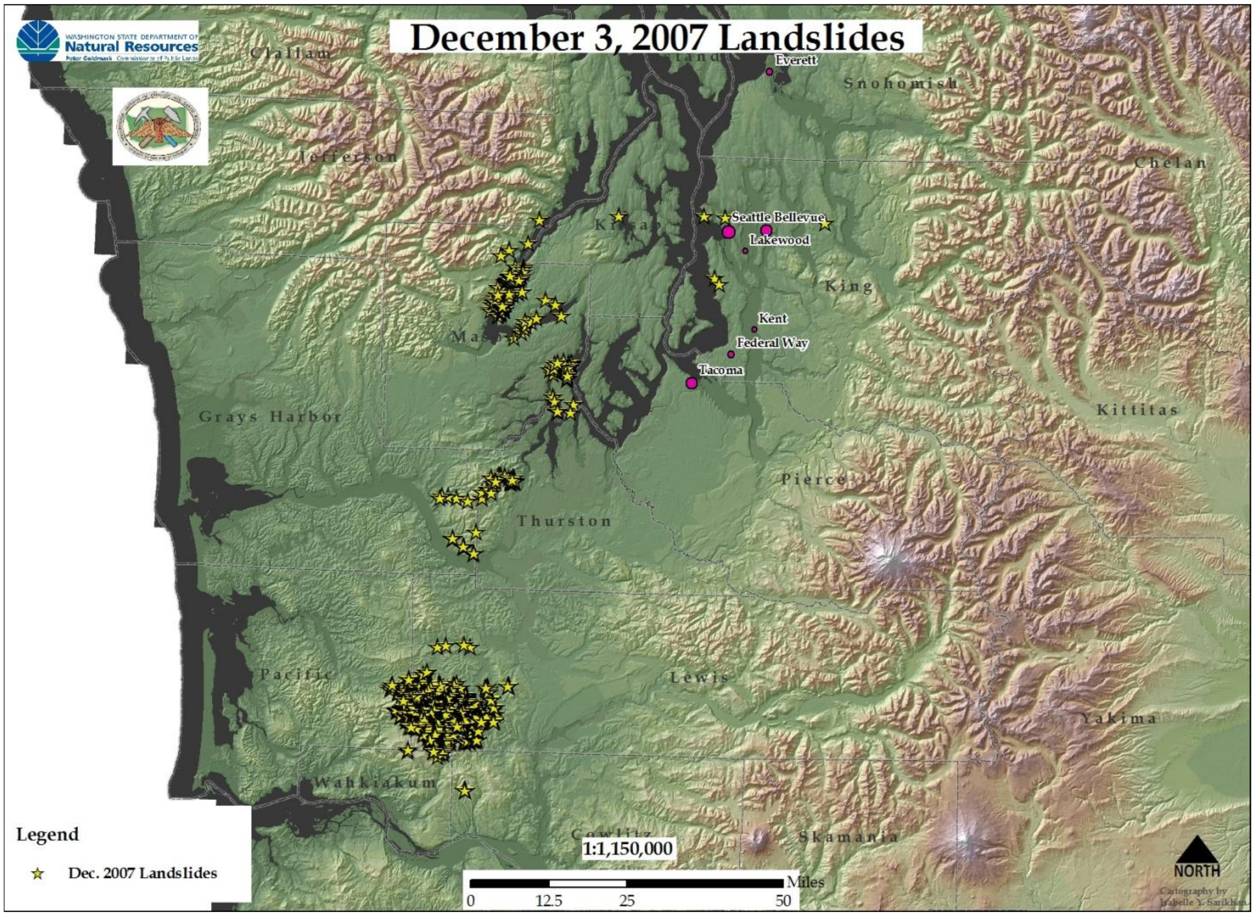


Figure 72 Landslide initiation points from the December 3, 2007 Storm

Numerous landslides occurred in Capital Forest, one destroying the Ranch House BBQ business on Highway 8. Landslides also occurred at the interchange of Highway 101 and Highway 8, temporarily closing both. Landslides blocked Highway 101 north of Skokomish River. Numerous debris flows, debris avalanches, and hyperconcentrated flows blocked the freeway, isolating communities along Hood Canal. Holiday Beach was hardest hit, with at least eight houses affected by a hyperconcentrated flow through the middle of the community. On the eastern shores of Hood Canal, numerous debris flows closed the North Shore Road and destroyed one house. Only eight landslides were recorded in the Seattle-Everett area, most of them localized, and caused minor impacts to roads.

January 2009 Storms

The January 7th-8th Storm was a typical Pineapple Express storm, bringing warm rains that originated from around Kauai (Hawaiian Islands) and rapidly melting snow in a rain-on-snow event. The rainfall followed lowland snow in the Puget Sound region from December 2008 into January 2009, resulted in high amounts of flooding and saturation of soils. Washington State Geological Survey reported through field and aerial surveys that the storm caused over 1,500 landslides greater than 5,000 square feet in size. The flooding resulted in the largest evacuation in state history, forcing more than 30,000 people living in the Puyallup River area to flee. Landslides were reported from Cowlitz County to Whatcom County and from the coast and into Kittitas and Yakima counties. The most intense rainfall occurred along the Cascade Mountains, where the majority of landslides also occurred. The hardest hit areas were eastern Lewis, Skagit, and Whatcom Counties.

In Lewis County, hundreds of debris flows between Morton and Randle flowed into the valley, destroying houses and blocking Highway 12. The debris flows were very long reaching, often transforming into hyperconcentrated flows on the valley floor, and moving for miles downstream. Many of the hyperconcentrated flows were channelized into roadways by plowed snow from earlier snow storm events. Over 500 landslides were recorded in Eastern Lewis County with an unknown number of houses damaged. No deaths were reported.

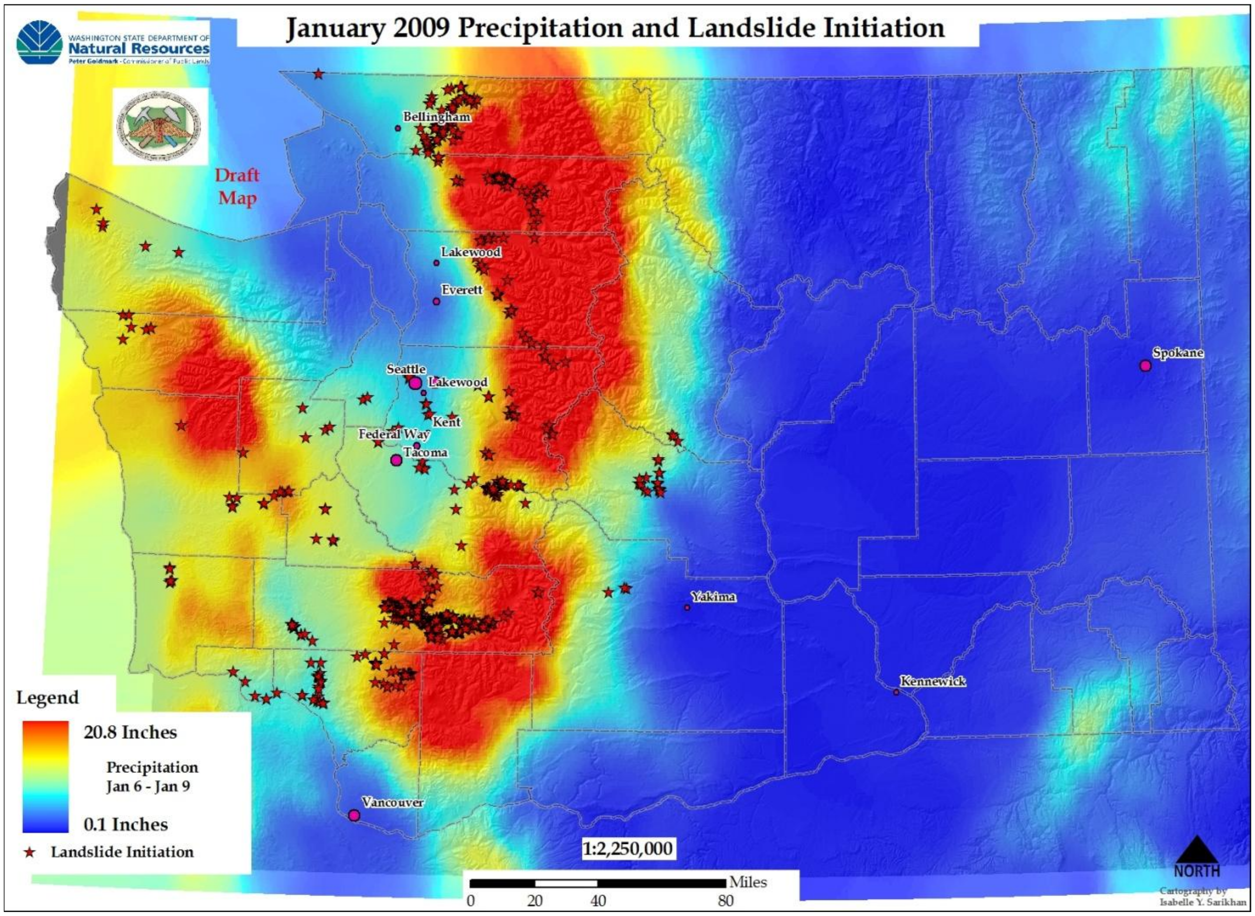


Figure 73 January 7-8, 2009 storm and landslide initiation.

In Skagit and Whatcom Counties, debris flows blocked roads and damaged or destroyed houses. In Skagit County, the town of Concrete had several debris flows damage houses, forcing an evacuation away from the surrounding unstable slopes. In Whatcom County, debris flows were most concentrated in the Chuckanut Formation. Debris flows generally were isolated into channels that flowed onto alluvial plains. Approximately 300 to 500 landslides occurred in Skagit and Whatcom Counties.

In Kittitas County, a large debris avalanche formed on the Hyak Ski area on Snoqualmie Pass. The landslide destroyed numerous buildings and ski infrastructure. Numerous landslides around Blewett Pass blocked Highway 97, resulting in its closure. In the Pierce, King, and Snohomish Counties, landslides occurred mostly in the Cascade foothills. Highway 410 near Greenwater was closed due to numerous debris flows across the highway, isolating the town of Greenwater. In Clark County, landslides dotted around the I-5 corridor and numerous landslides occurred in the Kelso and Longview area. Numerous landslides were also recorded on or near Highway 504 (Spirit Lake Highway). A smaller number of landslides occurred in many of the other counties within Western Washington.

Highway infrastructure was most impacted along SR 112 in the vicinity of MP 37 where 500 feet of roadway dropped up to 8 feet, closing the highway indefinitely; the southern portion of US Highway 101 in the vicinity of MP 43 and 60.6; the Cowlitz River valley where several landslides and one major rockfall closed the highway for two days between Mossy Rock and Randal; the Tilton River drainage where the SR 508 bridge footing was scoured at Morton and a landslide subsided up to one foot on the west side of Bear Canyon; the Lewis River drainage where SR 503 was temporary closed by landslides in the vicinity of MP 30.3 and 37.7; the Snoqualmie River drainage where a landslide occurred on Interstate 90 in the vicinity of MP 36; the Cedar River drainage where the Cedar River bridge approach wall failed on SR 169 from river scour and a retaining wall near the Issaquah-Hobart interchange on SR 18 was undermined; near McCleary a landslide impacted the roadway in the vicinity of MP 8.5 on SR 108; and another landslide occurred adjacent to a home on SR 122 in the vicinity of MP 6.2.

Perhaps the most damaging part of the January 2009 storm was the potential reactivation of movement of the landslide underneath Howard Hansen Dam, which might have caused a subterranean leak on the dam in King County. The leak was detected shortly after the January storm. The dam prevents wide scale flooding in the Kent Valley, but at a weakened strength, the dam may be forced to release flood waters.

On January 16th, a landslide on the Spokane River arm of Lake Roosevelt resulted in an inland tsunami, creating a wave about 30 feet high. The tsunami destroyed numerous docks and did some damage to houses along the waterfront. A rockslide on March 23rd blocked the Entiat River Road in Chelan County. The landslide was about 11 miles northwest of Entiat. A hyperconcentrated flow moved through Glendale on south Whidbey Island on April 3rd, the result of a beaver dam-burst flood. A 100 to 150 foot section of the road on Glendale Creek gave way after a beaver dam collapsed, resulting in the hyperconcentrated flow. In Chelan County, an irrigation pipe leak resulting in a landslide on April 21st. The landslide occurred on the 1000 block of Vista Place and resulted in damage to a fence and tree. Two landslides on April 25th moved across Brender Canyon Road near Cashmere, Chelan County. One of the landslides was reported to be about 20 feet wide by about 4 feet deep. A rockslide on Interstate 90 temporarily closed eastbound lanes for five hours on May 12th. The slide was mostly the result of one boulder, with a minor amount of other debris.

A debris flow on July 29th closed the North Cascades Highway near Rainy Pass. The landslide was triggered following several days of thunderstorms. The landslide was reported to be about 900 feet long by about 10 feet deep along the Highway. An abutment along a railroad track in Stevens County gave way on August 6th, resulting in a small landslide. A train was derailed as a result of the damaged railroad tracks. On August 25th, a landslide on the Spokane River arm of Lake Roosevelt resulting in an inland tsunami. The tsunami damaged the Porcupine Bay Campground and injured two children.

A massive landslide started to move on October 10th west of Naches near the town of Nile. On October 11th, the landslide catastrophically failed, diverting the Naches River covering Highway 410, and damaging 6 houses by ground deformation and over 20 homes by flooding.

Figure 74 An oblique photo of the Nile Landslide, photo by Jack Powell, DNR

Following the landslide movement Yakima County purchased 60 acres of land that included several homes at a cost of $1.78 million to realign the Naches River channel and a new road. WSDOT constructed a temporary route for Highway 410 on the other side of the valley. In response to the danger of the landslide, WSDOT, DNR, and the University of Washington monitored the landslide for movement. A radar system was employed to monitor landslide movement, monuments were set up on the landslide, and portable seismometers were utilized to detect any precursor to further movement of the landslide. A new Highway 410 route across the toe of the landslide opened in August 2012.

Storms from November 15 - 24 triggered a handful of landslides. On November 16th, a landslide occurred on Hwy 101, near Ayock, another at 29th Court NW near Shawnee Drive, which damaged a garage, and a deep-seated earthflow in Clallam County on a forest service road. Continued rains triggered a landslide on November 17th along the tracks of Seattle, 4 miles north of Carkeek Park.

Landslides in 2010[192]

On January 13th along the 6000 block of Beach Drive in Seattle, a landslide temporarily closed the road. On January 14th a landslide shut down westbound SR 16 in Auburn. Sound Transit cancelled service on

January 19th because of a mudslide in the south Seattle area. A weekend mudslide at North Waterview Street in Tacoma caused the road to collapse and break a major water main on October 12th.

The National Weather Service reported 29 landslides after the weekend storm of December 11th - 12th. Landslides impacted 17 city or county roads, seven highways, three railways, two homes, and two power lines. Amtrak service was canceled between Seattle and Portland. A landslide crashed into a house at Riviera Place NE along Lake Washington on December 13th. Nine slides closed the Burke-Gilman trail in various places. There was another slide at 12500 block of Edgewater Lane NE in Seattle. State Route 2 was closed near Muddy Creek Campground because of a landslide while SR11 Chuckanut Drive in Whatcom County also closed because of a landslide.

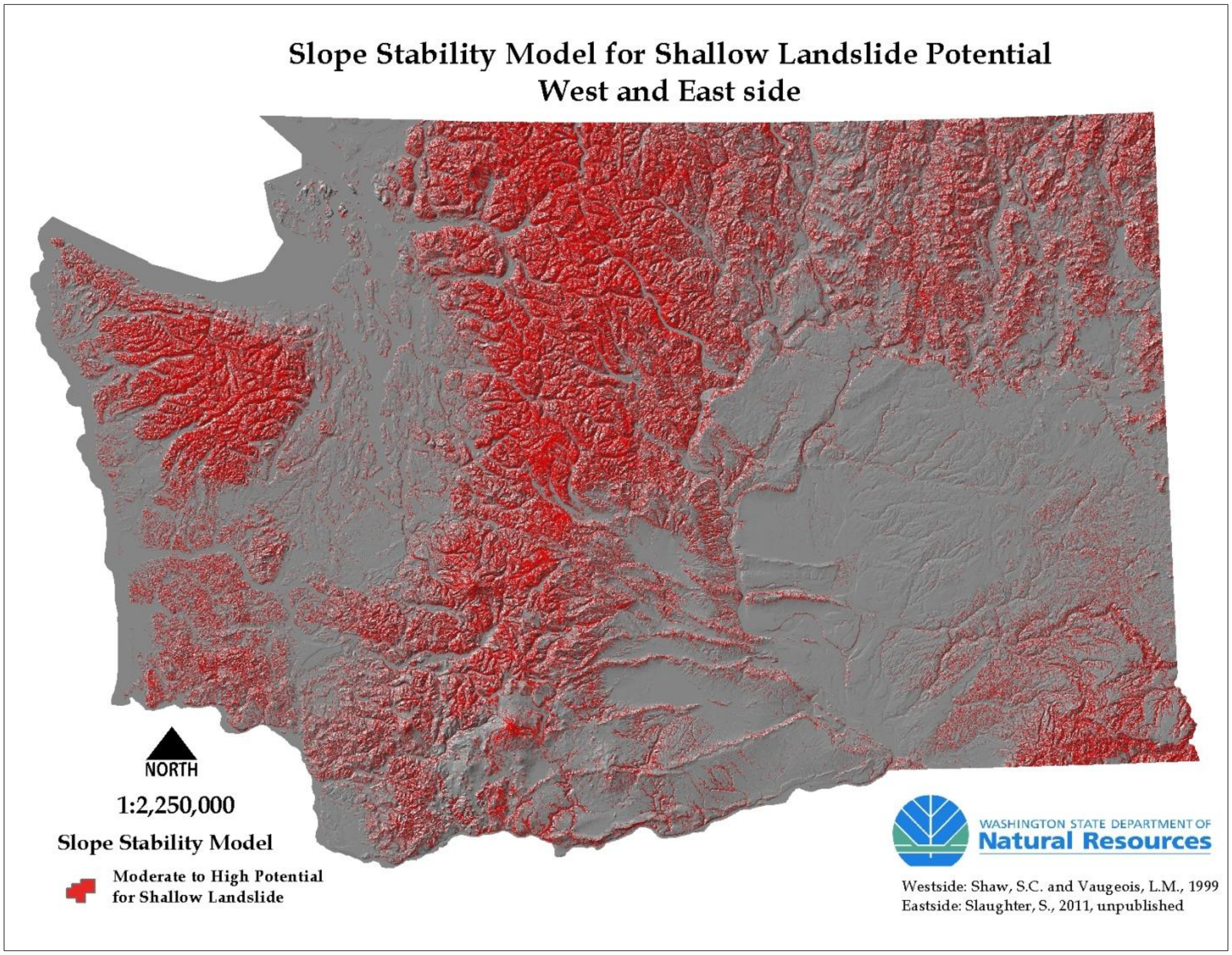
Landslides in 2011[193]

January 14th mudslide temporarily closed State Route 101 in Mason County and another landslide closed the West Valley Highway in Sumner for several days. A mudslide along the main railroad line near Everett suspended passenger rail service between Seattle and Vancouver, B.C. On February 12, a mudslide north of Vancouver, WA near Felida shut down Amtrak train service between Portland and Seattle. Another slide on March 1st closed the railroad to passenger traffic between Portland and Seattle. On March 14th a mudslide damages a home in Edmonds. Amtrak service between Everett and Seattle has been suspended numerous times because of slides during the month of March. On March 15th, landslides force evacuation of nine homes along Gertie Johnson Road on Bainbridge Island. Gertie Johnson is on the same hillside that slid on to Rolling Bay Walk in 1997, killing a Bainbridge High School teacher, his wife, and their two young sons. On May 17th a large debris flow covered the North Cascade Highway SR 20. On June 10th a mudslide covered Leavenworth's Icicle Road stranding 30 people above the slide. On July 6th a mudslide cut power to about 1,400 residents in Kent. On November 29th a slide closed the South Skagit Highway near mile marker 12. The Seattle-Everett railroad route had nearly 100 slides in 2011, the most in 20 years per Gus Melonas, a spokesman for the Burlington Northern Santa Fe railroad.

Landslides in 2012[194]

On January 23rd a water main break caused a landslide that forced evacuations for four homes. On February 22nd, a slide closed the railroad tracks between Everett and Seattle while another slide damaged several homes in Stanwood. A mudslide wiped out one house and damaged another near Port Susan later that day. On February 23rd, a landslide on private property near Morton diverted water in a culvert which damaged a nearby home. On April 27th a large mudslide closed State Route 410 in the Nile Valley. A slide occurred at the same location the previous year. The mudslide area is 19 miles west of a landslide that wiped out SR 410 three years ago. On July 17th two landslides close State Route 821 in the Yakima River Canyon. The slides occurred in the same area as a massive 1998 landslide buried the highway for two weeks.

Figure 75 Slope Stability Model



Jurisdictions Most Threatened and Vulnerable to Landslide Hazards

Analysis of risk to local jurisdictions is a difficult process. Currently, there are no comprehensive statewide landslide hazard maps. However, models exist to aid in detecting potential areas more susceptible to landslides in some locations. All counties in Washington State have some landslide hazard and risk. In Washington State, landslide risk is higher in western Washington due to the higher amount of precipitation. Water and gravity are the main drivers of landslides. In Eastern Washington, the landslide risk is high during storm events (especially spring and summer thunderstorms) and in places where irrigation is near bluffs or near or on deep-seated landslides. Earthquakes have the potential to cause landslides in Eastern and Western Washington.

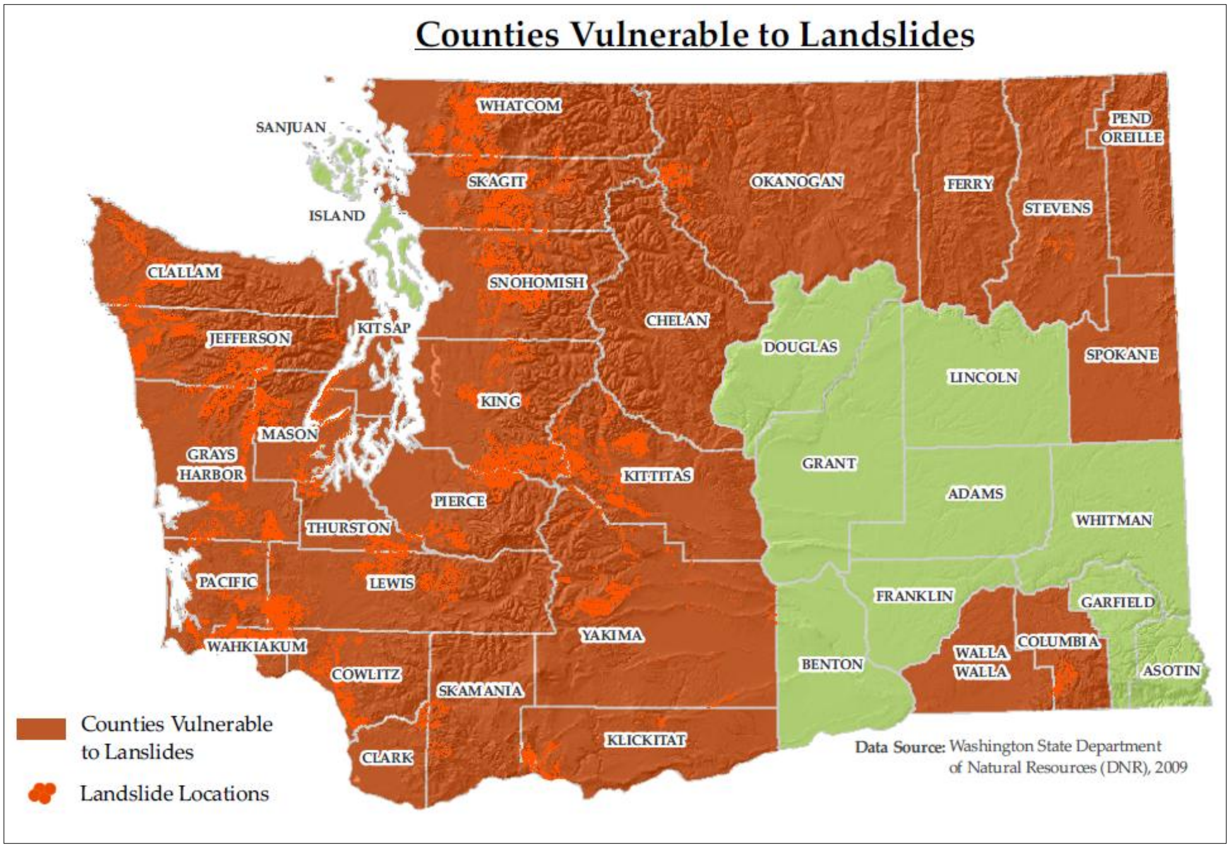


Figure 76 Counties Vulnerable to Landslide Hazards. Counties within in Washington State that contain known landslides are considered at-risk to future landslide activity.

Since no statewide landslide susceptibility map exists, a detailed analysis of public facilities is difficult. However, a simple analysis of public facilities on or nearby landslides indicates 23 facilities potentially at risk of future landslide activity. The risk could include reactivation of a deep-seated landslide or in areas susceptible to shallow landslides, such as debris flows. This simple analysis does not exclude features not shown on the map from landslide risk.

Figure 77 Public facilities in or within 100 feet of a landslide within the Washington Geologic Surveys landslide database. These facilities are potentially at risk for future landslide activity.

Utilizing the Washington State Office of Financial Managements 2009 dataset of state leased and owned facilities, an analysis was performed to determine which, if any, state facilities may be at risk to a future landslide. For the state leased facilities in this dataset, 42 were determined to be within 500 feet of a landslide and may therefore be at risk to future landslide activity. These state owned facilities represent over 123,000 square feet of office space with a total value of over $2.4 million dollars. An identical analysis of state leased facilities was performed, but no state leased facilities were determined to be within the specified distance of any known landslide location contained in the landslide database.

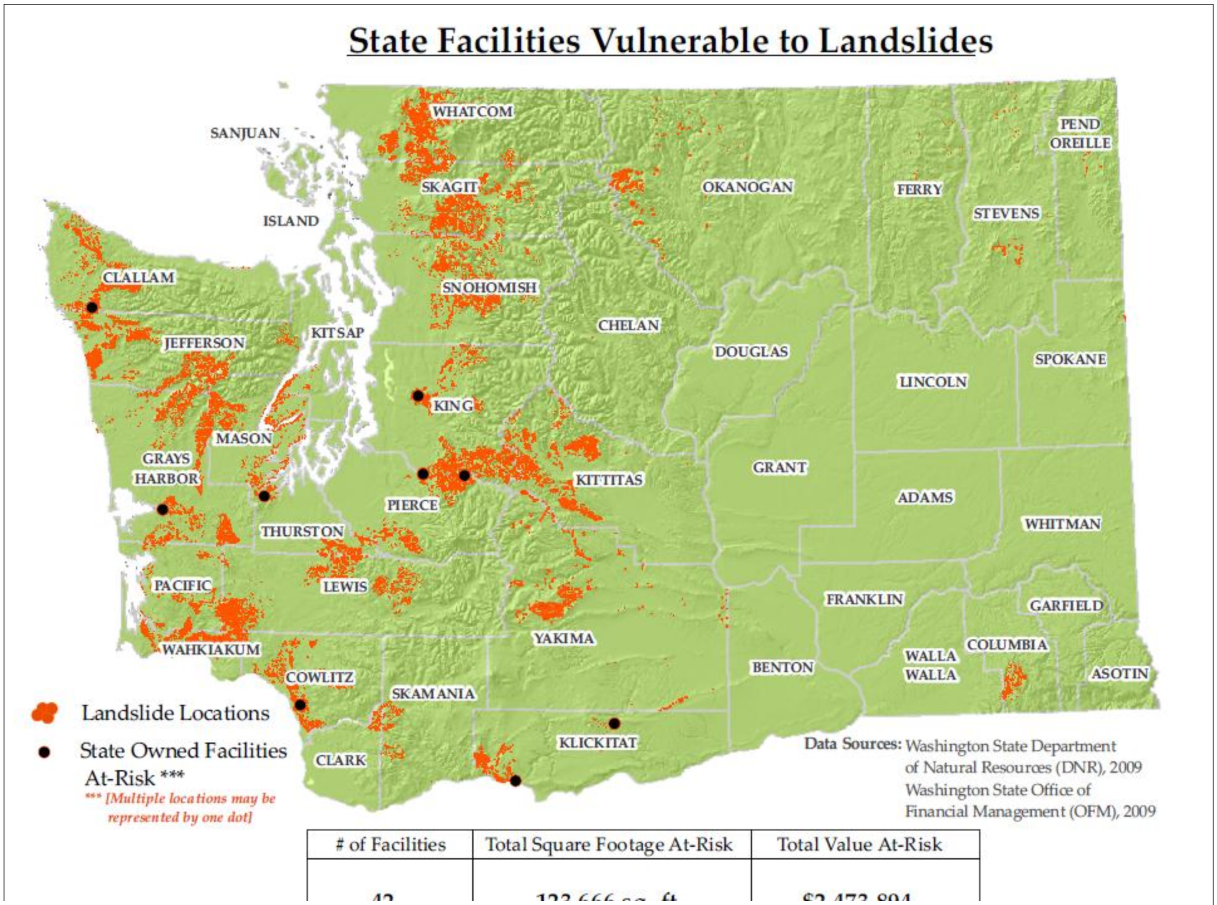


Figure 78 State Owned Facilities within 500 feet a location of a known landslide according to the Washington Geologic Survey's 2009 Landslide Database at 24K.

Table 74 State Agency Structures At Risk			
Number and Function of Buildings	No. of Affected Staff / Visitors / Residents	Approx. Value of Owned Structures	Approx. Value of Contents All Structures
42	N/A	$2.4 million	N/A

Nine state highways considered emphasis corridors because of their importance to movement of people and freight are potentially at risk to landslide and ground failure:

- Interstate 5
- Interstate 82
- Interstate 90
- U.S. Highway 2
- U.S. Highway 12
- U.S. Highway 97
- U.S. Highway 101
- U.S. Highway 395
- State Route 20

Additionally, ferry landings in Anacortes, Bainbridge Island, Bremerton, Clinton, Fauntleroy, Keystone, Mukilteo, Port Townsend, the San Juan Islands, Seattle, Southworth, Tacoma, and Vashon Island are potentially at risk because of their construction on poor soils in shoreline areas.

Potential Climate Change Impacts [195] [196]

Vulnerability to landslide hazards is a function of location, type of human activity, use, and frequency of landslide events. The effects of landslides on people and structures can be lessened by total avoidance of landslide hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity. Local governments can reduce landslide effects through land-use policies and regulations. Individuals can reduce their exposure to hazards by educating themselves on the past history of a site and by making inquiries to planning and engineering departments of local governments. In addition, it is highly advised to consult the professional services of an engineering geologist, geotechnical engineer, or a civil engineer, who can properly evaluate a site, built or un-built.

With the advent of global warming coming into worldwide focus, it is only fitting to discuss its possible effects on landslide hazards. Antoni Lewkowicz of the University of Ottawa has studied several northern landslides and rockslides that he says can be at least partially attributed to thinning and weakening of ice or permafrost caused by climate change. Other experts from the United Nations University say "If climate change predictions are accurate you will expect … more intense and extreme rainfalls which could result in more landslides throughout the world."

Landslide hazards can be reduced by avoiding construction on steep slopes and existing landslides or by stabilizing the slopes. Slope stability will increase with one or more of the following actions: when ground water can be prevented from rising in the landslide mass by covering the landslide with an impermeable membrane, directing surface water away from the landslide area, draining the ground water away from the slide area, or minimizing surface irrigation. Slope stability can also increase when a retaining structure and/or the weight of a soil/rock berm are placed at the toe (bottom) of the landslide or when mass is removed from the top of the slope. City, county, and state mitigation plans can be a further source of information for strategies to reduce the impacts and potential for landslides and their associated hazards in Washington.

Although the physical cause of many landslides cannot be removed, geologic investigations, good engineering practices, and effective enforcement of land-use management regulations can (greatly) reduce landslide hazards.

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Severe Storm

Severe Storm					
	Frequency	50+ yrs	10-50 yrs	1-10 yrs	Annually
	People	<1,000	1,000-10,000	10,000-50,000	50,000+
	Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
	Environment	<10%	10-15%	15%-20%	20%+
	Property	<$100M	$100M-$500M	$500M-$1B	$1B+
	Hazard scale		< Low to High >		

Risk Level

Frequency – Severe storms, which include any or a combination of: thunderstorms, hail, wind storms, lightning, or a tornado, happen annually in Washington.

People – Looking at past history of injuries and deaths due to severe storms in Washington, the minimum threshold of a thousand injuries for this category is not met.

Economy – According to the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center, Washington has not experienced a severe weather event that totaled losses that met or exceeded the minimum dollar amount /percentage for this category. [197]

Environment – Severe storms do affect the environmental landscape of Washington, but their effect does not meet the minimum threshold for this category.

Property – Severe storms can have a large impact on the property of the state, both residential and commercial. The December 2006 windstorm affected all 39 counties and the estimate for damage is still being tallied and is greater than $50 million. Total property damage from the greatest windstorm to hit Washington is estimated at $235 million (1962 dollars). This was the Columbus Day Storm of October 1962, which was the strongest non-tropical storm to ever hit the contiguous 48 states.

HIVA Risk Classification for Severe Storm is 4A or Mitigation to Reduce Risk is Optional.

Figure 79 and Figure 80 below show previous occurrences of tornado and hail events, respectively, from 1960 to 2012 as reported by the National Climatic Data Center. It should be noted that the entire state is vulnerable to the severe storm hazard, including winds, lightning, snow, tornadoes, and hail, due to its atmospheric nature.

Figure 79 The severe storm element tornado was collected from the National Climatic Data Center website for the period of 1954-2012. Tornadoes for these years were in the value of F-0 to F-3 (Fujita Scale) or EF-0 to EF-1 (Enhanced Fujita)if recorded after January 2007.

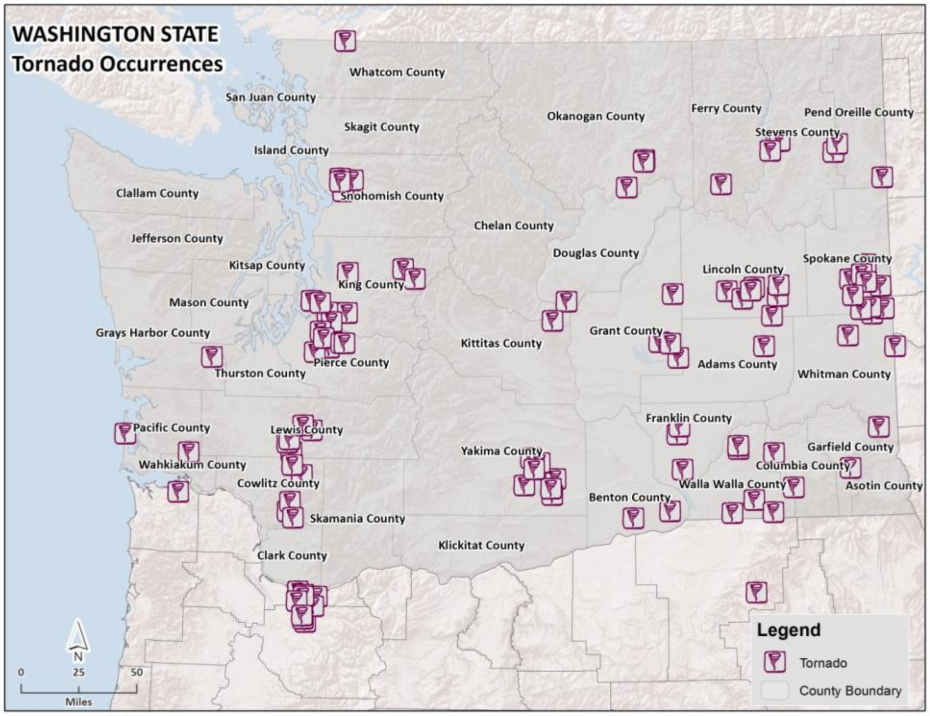
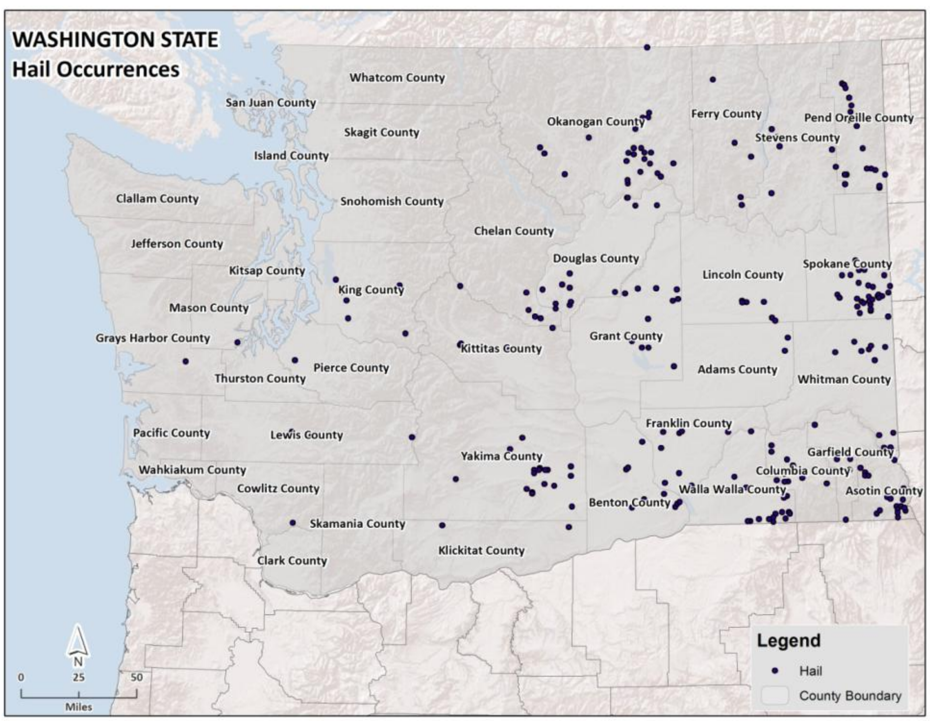


Figure 80 The severe storm element hail was collected from the National Climatic Data Center website for the period of 1955-2012. Hail for these years ranged in diameter from ½ to 2 inches.



Summary[198]

The hazard – For the purposes of this assessment, a Severe Storm is defined as an atmospheric disturbance featuring sustained strong winds (40+ MPH) and/or significant precipitation (rain or snow). Such events typically occur during the winter months and generally move into the State from the Pacific Ocean. They may include any or a combination of: thunderstorms, hail, wind storms, lightning, or tornadoes.

Previous occurrences – According to the National Weather Service, events meeting the Severe Storm definition have produced some of the most significant weather events in the 20th Century in Washington State, including snowstorms in January 1916 and January 1950; the Columbus Day Windstorm in October, 1962 (still the most dramatic weather ever to hit the State); the Inauguration Day Windstorm in January, 1993; the January 1997 Winter Storm; the December 2006 Hanukkah Eve Windstorm; the December 2007 windstorm and flood; the December 2008 snow storms; the January 2009 floods; the 2011 January ice storm; and the 2012 Ferry County wind storm. Many of these events have resulted in a presidential disaster declaration, emphasizing their severity. These events are described in detail below.

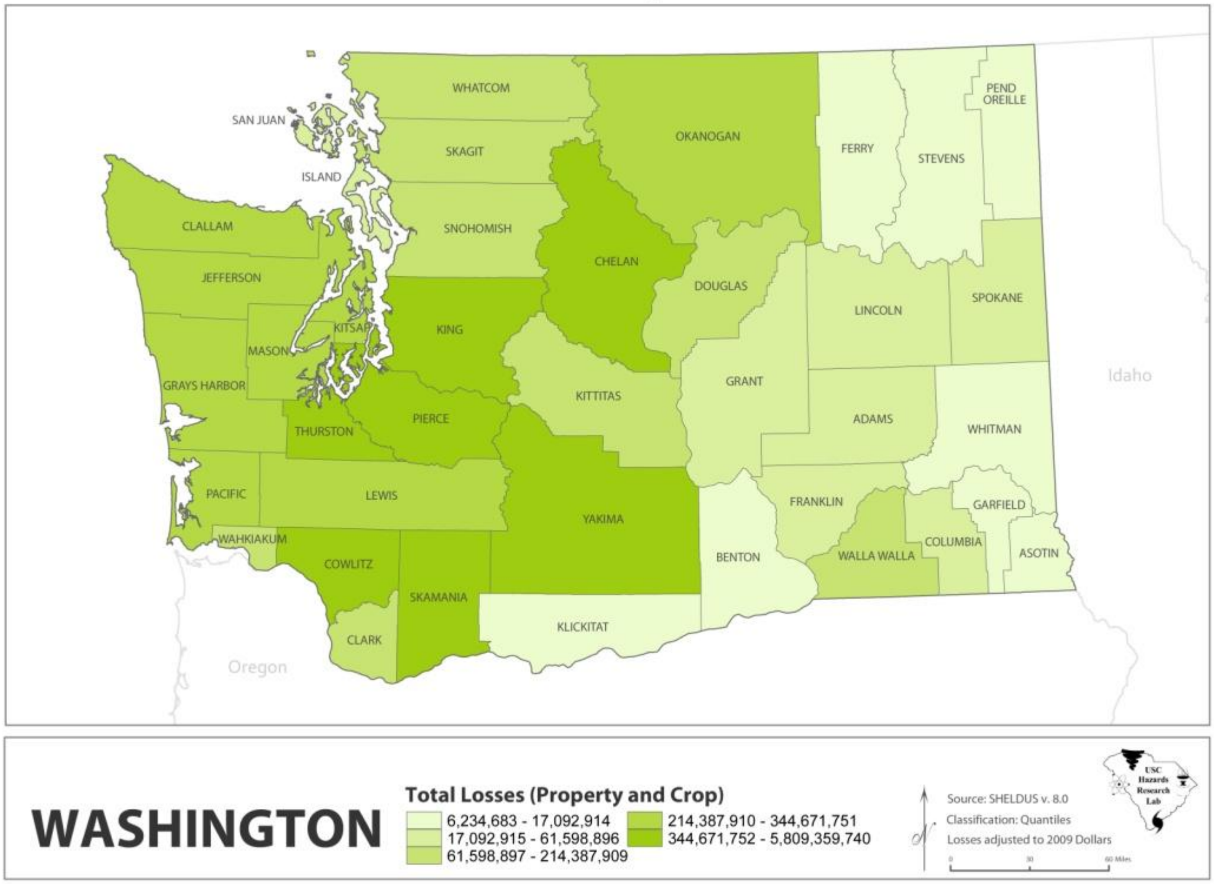
Probability of future events - Because of its location on the windward coast of the North Pacific Ocean and its mountainous topography which influences precipitation patterns, Washington State is assured of powerful Severe Storm events in the future.

Jurisdictions at greatest risk – While Severe Storms have impacted every corner of the State, counties most at risk include those along the Pacific Coast, counties within the Puget Sound basin, counties along the east slopes of the Cascade Mountains, and some counties in southeastern Washington as well as Spokane County.

Special note – This profile will not attempt to estimate potential losses to state facilities due to severe storm. The state does not have data on which to base a determination of which facilities might be most vulnerable to either high winds or winter storm. However, all facilities are considered at risk to this hazard.

Figure 81 shows the economic losses from all weather-related hazard damage (including property, timber, and crops) from 1960-2009

Economic Losses from Hazard Events, 1960-2009



The Hazard [199]

All areas of Washington State are vulnerable to severe weather. Typically, a severe storm can cause major impacts to transportation, infrastructure and services, and loss of utilities. Most storms move into Washington from the Pacific Ocean. A severe storm is defined as an atmospheric disturbance that results in one or more of the following phenomena: high winds, heavy snow, large hail, thunderstorms, lightning, tornados, rain, snow, or other mixed precipitation. These phenomena are defined by the National Weather Service:

High Winds – Sustained wind speeds of 40 mph or greater lasting for 1 hour or longer, or winds of 58 mph or greater for any duration, not caused by thunderstorms.

Severe Thunderstorm – A thunderstorm that produces a tornado, winds of at least 58 mph (50 knots), and/or hail at least 1 inch in diameter. A thunderstorm with wind equal to or greater than 40 mph (35 knots) and/or hail at least ½ inches in diameter is defined as approaching severe.

Tornado – A violently rotating column of air, usually pendant to a cumulonimbus (type of cloud), with circulation reaching the ground. It nearly always starts as a funnel cloud and may be accompanied by a loud rotating noise. On a local scale, it is the most destructive of all atmospheric phenomena.

Heavy Snow – This generally means: a snowfall accumulating to 4" or more in depth in 12 hours or less or a snowfall accumulating to 6" or more in depth in 24 hours or less.

Lightning – A visible electrical discharge produced by a thunderstorm. The discharge may occur within or between clouds, between the cloud and air, between a cloud and the ground or between the ground and a cloud.

Hail – Showery precipitation in the form of irregular pellets or balls of ice more than 5 mm in diameter, falling from a cumulonimbus cloud.

Winter storm – A storm with significant snowfall, ice, and/or freezing rain; the quantity of precipitation varies by elevation. Heavy snowfall is 4 inches or more in a 12-hour period, or 6 or more inches in a 24-hour period in non-mountainous areas; and 12 inches or more in a 12-hour period or 18 inches or more in a 24-hour period in mountainous areas.

Note: Although flooding is a result of severe rainstorms, see the Flood Hazard Profile for a complete discussion on the flood hazard.

Hazardous Weather Seasons[200]

The primary flood season in Western Washington (west slops of Cascades) is November through February while the primary flood season in Eastern Washington (east slopes of Cascades) is May and June. The windstorm season for the state is October through March. The snow season in western Washington is mid November through mid March while the snow season for Eastern Washington is November through March. The snow season for the state's mountains is mid October through May.

Washington State's Climate[201]

The location of the State of Washington on the windward coast in mid-latitudes is such that climatic elements combine to produce a predominantly marine-type climate west of the Cascade Mountains while east of the Cascade Mountains, the climate possesses both continental and marine characteristics.

The state's climate is impacted by two significant factors of mountains and the North Pacific Ocean.

The Olympic Mountains and the Cascade Mountains affect rainfall. The first major release of rain occurs along the west slopes of the Olympics, and the second is along the west slopes of the Cascade Range. Additionally, the Cascades are a topographic and climatic barrier. Air warms and dries as it descends along the eastern slopes of the Cascades, resulting in near desert conditions in the lowest section of the Columbia Basin in eastern Washington. Another lifting of the air occurs as it flows eastward from the lowest elevations of the Columbia Basin toward the Rocky Mountains. This results in a gradual increase in precipitation in the higher elevations along the northern and eastern borders of the state.

Location and intensity of semi-permanent high and low-pressure areas over the North Pacific Ocean.

- During the summer and fall, circulation of air around a high-pressure area over the North Pacific brings a prevailing westerly and northwesterly flow of comparatively dry, cool, and stable air into the Pacific Northwest. As the air moves inland, it becomes warmer and drier, resulting in a dry season.
- In the winter and spring, the high pressure resides further south while low pressure prevails in the Northeast Pacific. Circulation of air around both pressure centers brings a prevailing southwesterly and westerly flow of mild, moist air into the Pacific Northwest. Condensation occurs as the air moves inland over the cooler land and rises along the windward slopes of the mountains. This results in a wet season beginning in late October or November, reaching a peak in winter, gradually decreasing by late spring.

West of the Cascade Mountains, summers are cool and relatively dry while winters are mild, wet, and generally cloudy. Generally, in the interior valleys, measurable rainfall occurs on 150 days each year and on 190 days in the mountains and along the coast. Thunderstorms over the lower elevations occur up to 10 days each year and over the mountains up to 15 days. Damaging hailstorms rarely occur in most localities of western Washington. During July and August, the driest months, two to four weeks can pass with only a few showers; however, in December and January, the wettest months, precipitation is frequently recorded on 20 to 25 days or more each month.

The range in annual precipitation is from about 20 inches in an area northeast of the Olympic Mountains to 150 inches along the southwestern slopes of these mountains. Snowfall is light in the lower elevations and heavy in the mountains. During the wet season, rainfall is usually of light to moderate intensity and continuous over a period of time, rather than heavy downpours for brief periods; heavier intensities occur along the windward slopes of the mountains.

The strongest winds are generally from the south or southwest and occur during the fall and winter. In interior valleys, sustained wind velocities usually reach 40 to 50 mph each winter, and 75 to 90 mph a few times every 50 years. The highest summer and lowest winter temperatures generally occur during periods of offshore easterly winds.

The climate east of the Cascade Mountains has characteristics of both continental and marine climates. Summers are warmer, winters are colder, and precipitation is less than in western Washington. Extremes in both summer and winter temperatures generally occur when air from the continent influences the inland basin.

In the driest areas, rainfall occurs about 70 days each year in the lowland and about 120 days in the higher elevations near the eastern border and along the eastern slopes of the Cascades. Annual precipitation ranges from seven to nine inches near the confluence of the Snake and Columbia Rivers in the Tri-Cities area, 15 to 30 inches along the eastern border and 75 to 90 inches near the summit of the Cascade Mountains. During July and August, four to eight weeks can pass with only a few scattered showers. Thunderstorms, most as isolated cells, occur on one to three days each month from April through September. A few damaging hailstorms are reported each summer.

During the coldest months, freezing drizzle occasionally occurs, as does a Chinook wind that produces a rapid rise in temperature. During most of the year, the prevailing wind is from the southwest or west. The frequency of northeasterly winds is greatest in the fall and winter. Sustained wind velocities ranging from four to 12 mph can be expected 60 to 70 percent of the time; 13 to 24 mph, 15 to 24 percent of the time; and 25 mph or higher, 1 to 2 percent of the time. The highest wind velocities are from the southwest or west and are frequently associated with rapidly moving weather systems. Extreme sustained wind velocities can be expected to reach 50 mph at least once in two years; 60 to 70 mph once in 50 years; and 80 mph once in 100 years.

Previous Occurrences

Washington has had several notable severe storm events in its history including severe snowstorms, tornadoes, and windstorms. The most notable snowstorm in Washington to date occurred during January and February of 1916. On February 1, 1916, Seattle recorded a record snowfall accumulation of 21.5 inches in a 24-hour period. Other parts of Washington received around 2 to 4 feet of snow for the entire winter.

Although far from the famous "tornado alley" of the Midwest United States, Washington has tornadoes. Washington's deadliest tornado outbreak occurred on April 5, 1972. On this day, an F-3 tornado (sustained winds of 158-206 mph) touched down in the City of Vancouver causing 6 deaths, 300 injuries and an estimated $50 million in damage. Later that same day, another F-3 tornado touched down west of Spokane in rural Lincoln County and an F-2 tornado (sustained winds of 113-157 mph) struck rural Stevens County. The state experienced another outbreak of tornadoes on May 31, 1997. On this day, a record six tornadoes touched down in Washington: four F-1 tornadoes (sustained winds of 73-112 mph) struck in Stevens and Spokane Counties and an additional two F-0 tornadoes (sustained winds of 40-72 mph) touched down, one in Vancouver and one in Tacoma. Besides tornadoes, these severe storms produced large hail up to 3 inches in diameter with heavy rain and wind gusts up to 80 mph.

Windstorms occur more often than tornadoes in Washington and cause millions of dollars in damage with each occurrence.

> The Columbus Day Windstorm that hit the Northwest on October 12, 1962 is the greatest windstorm to strike this area and has become the windstorm of which all others are compared. This storm was the strongest widespread non-tropical windstorm to hit the continental U.S. during the 20th century, with its effects felt from northern California to British Columbia. The storm claimed 46 lives and caused the loss of power to over 1 million homes. More than 50,000 homes were damaged costing an estimated $235 million (1962 dollars).
>
> The Inauguration Day Windstorm on January 20, 1993 (Federal Disaster #981) brought hurricane force winds (sustained winds or gusts of 74 mph or greater) to King, Mason, Lewis, Thurston, Snohomish, Pierce, and Wahkiakum Counties. This storm claimed 5 lives and resulted in the destruction of 52 homes and damaged an additional 249 homes and 580 businesses. Total damage resulting from this storm is estimated at $130 million.

The most powerful windstorm since the 1993 storm occurred in December of 2006 (Federal Disaster #1682) (Figure 5.7-2). This storm brought 90 mile per hour winds to Washington's coastline and wind gusts of up to 70 mph in the Puget Sound region. The storm also knocked out power to 1.5 million Washington residents with some not seeing electricity restored for 11 days. A federal disaster declaration was declared for all 39 of Washington's counties and estimated damages exceeded $50 million dollars.

Figure 82 Affects of December 2006 Windstorm. One of the may damaged homes resulting from falling trees due to strong winds from the storm.

A windstorm on July 20, 2012 hit Okanogan and Ferry Counties plus the Confederated Tribes of the Colville Reservation in eastern Washington (Federal Disaster #DR-4083). Damage estimates were at $8.4 million for Ferry County and $1.1 million for Okanogan County

Significant Severe Storms in Washington State – 1900 to Present

January/February 1916 – Seattle's Greatest Snowstorm[202] - One of the top 10 weather events in Washington State during the 20th Century according to the National Weather Service, Seattle Forecast Office. Seattle's snowfall in January was 23 inches, and February snowfall was 35 inches, for a two-month total of 58 inches. Seattle recorded its maximum snowfall ever in a 24-hour period, with 21.5 inches on February 1. Other parts of western Washington received between two to four feet of snow. Winds created snowdrifts as high as five feet. The region was crippled, with transportation essentially halted.

May/June 1948 – Greatest Spring Snowmelt Flooding[203] -One of the top 10 weather events in Washington during the 20th Century, according to the National Weather Service, Seattle Forecast Office. Snowmelt flooding broke lake and river records in Eastern Washington and along the Columbia River to the Pacific Ocean. Flood lasted 45 days. Vancouver, Camas, Kalama, and Longview suffered flood damage.

January 13, 1950 – The January 1950 Blizzard[204] - One of the top 10 weather events in Washington during the 20th Century, according to the National Weather Service, Seattle Forecast Office. On this date, 21.4 inches of snow fell in Seattle, the second greatest 24-hour snowfall recorded. The snowfall was accompanied by 25-40 mph winds. The storm claimed 13 lives in the Puget Sound area. January had 18 days with high temperatures of 32 degrees or lower. The winter of 1949-50 was the coldest winter on record in Seattle, with an average temperature of 34.4 degrees. Eastern Washington, North Idaho, and parts of Oregon also were paralyzed by the snow – some lower-elevation snow depths reached nearly 50 inches and temperatures plunged into minus teens and twenties. Several dozen fatalities occurred.

October 12, 1962 – The Columbus Day Wind Storm[205, 206]- The top weather event in Washington during the 20th Century, according to the National Weather Service, Seattle Forecast Office. This storm is the greatest windstorm to hit the Northwest since weather recordkeeping began in the 19th century, and called the "mother of all wind storms" in the 1900s. All windstorms in the Northwest are compared to this one. The Columbus Day Storm was the strongest widespread non-tropical windstorm to strike the continental U.S. during the 20th century, affecting an area from northern California to British Columbia.

The storm claimed seven lives in Washington State; 46 died throughout the impacted region. One million homes lost power. More than 50,000 homes were damaged. Total property damage in the region was estimated at $235 million (1962 dollars). The storm blew down 15 billion board feet of timber worth $750 million (1962 dollars); this is more than three times the timber blown down by the May 1980 eruption of Mount St. Helens, and enough wood to replace every home in the state.

Highest recorded wind speeds (before power went out at recording stations) were Naselle, Washington Coast – gust to 160 mph; Bellingham and Vancouver – gusts of 113 mph; Renton – gust of 100 mph; and Tacoma – gust of 88 mph.

April 5, 1972 – Washington's Deadliest Tornado Outbreak[207, 208] - One of the top 10 weather events in Washington during the 20th Century, according to the National Weather Service, Seattle Forecast Office. Three tornadoes touched down in Washington State on this day: An F3 tornado touched down in Vancouver; it swept through a grocery store, bowling alley, and grade school near where Vancouver Mall is today. It caused six deaths, 300 injuries, and $50 million in damage. Later that day, another F3 tornado touched down west of Spokane near Davenport, and an F2 tornado struck rural Stevens County. Numerous severe thunderstorms with large hail and damaging winds were reported over other areas of eastern Washington. An F3 tornado (prior to 2008) has winds of 158-206 mph, and is capable of severe damage. An F2 tornado has winds of 113-157 mph and is capable of considerable damage. Because of these tornados, Washington led the nation in tornado deaths in 1972.

December 1982 [209] - Federal Disaster #676. Disaster assistance provided – $1.7 million. Small Business Administration loaned $1 million to home and business owners for damages. Severe storm and coastal flooding affected Whatcom County. Four persons injured and 122 people evacuated; 129 homes and 113 businesses damaged; and $1.7 million in public facility damage.

November 1990 – Statewide Flooding[210, 211]- Federal Disaster #883. Stafford Act disaster assistance provided – $57 million. One of the top 10 weather events in Washington during the 20th Century according to the National Weather Service, Seattle Forecast Office. Widespread, major flooding on western Washington rivers and several eastern Washington rivers. This storm caused two deaths. Damage estimated at $250 million. The Interstate 90 Lake Washington floating bridge between Seattle and Mercer Island sank during this storm event.

December 1990 – Severe Storm - Federal Disaster #896. Stafford Act disaster assistance provided – $5.1 million. Floods, snow, and high winds affected the counties of Island, Jefferson, King, Kitsap, Lewis, Pierce, San Juan, Skagit, Snohomish, and Whatcom.

January 20, 1993 – The Inauguration Day Wind Storm[212, 213] - Federal Disaster #981. Stafford Act disaster assistance provided – $24.2 million. Hurricane force winds swept King, Lewis, Mason, Pierce, Snohomish, Thurston and Wahkiakum counties. This storm claimed five lives. More than 870,000 homes and businesses lost power. Fifty-two single-family homes, mobile homes, and apartment units were destroyed and 249 incurred major damage, many from falling trees and limbs. More than 580 businesses were damaged. Total damage in western Washington estimated at $130 million. Winds in Puget Sound area gusted to 70 mph. A gust at Cape Disappointment on the Washington Coast reached 98 mph.

February 1996 – Storm with Widespread Flooding, Snowmelt, Mudslides in Washington, Oregon, and Idaho[214, 215] - Federal Disaster #1100. Stafford Act disaster assistance provided – $113 million. Small

Business Administration disaster loans approved - $61.2 million. One of the top 10 weather events in Washington during the 20th Century according to the National Weather Service, Seattle Forecast Office. Heavy rainfall, mild temperatures and snowmelt caused flooding and mudslides in Adams, Asotin, Benton, Clark, Columbia, Cowlitz, Garfield, Grays Harbor, King, Kitsap, Kittitas, Klickitat, Lewis, Lincoln, Pierce, Skagit, Skamania, Snohomish, Spokane, Thurston, Wahkiakum, Walla Walla, Whitman and Yakima counties, and the Yakama Indian Reservation. This storm caused major flooding on rivers of western and southeast Washington. Mudslides occurred throughout the state. Three deaths and 10 people were injured. Nearly 8,000 homes damaged or destroyed. Traffic flow - both east and west, and north and south, along major highways - was shut down for several days. An avalanche closed Interstate 90 at Snoqualmie Pass. Mudslides in Cowlitz County and flooding in Lewis County closed Interstate 5. Damage throughout the Pacific Northwest estimated at $800 million.

November 1996 – Spokane Area Ice Storm[216, 217] - Federal Disaster #1152. Stafford Act disaster assistance provided – $11.9 million. Heavy rain, freezing rain and snow fell in Spokane, Pend Oreille, and Klickitat counties. Up to three inches of ice was deposited on trees, vehicles, buildings, etc., across much of the populated areas of Spokane County. More than 100,000 homes and businesses lost power; some were without power for up to nine weeks. Power outage affected water and sewage pumping systems. Spokane International Airport was closed for two days due to power outage. Four people died and damage estimated at more than $22 million dollars.

December 1996 - January 1997 – Ice, Wind, Flooding, Snowloading, Landslides[218] - Federal Disaster #1159. Stafford Act disaster assistance provided – $83 million. Small Business Administration loans approved – $31.7 million. Saturated ground combined with snow, freezing rain, rain, rapid warming, and high winds within a five-day period produced flooding and landslides. Impacted counties – Adams, Asotin, Benton, Chelan, Clallam, Clark, Columbia, Cowlitz, Douglas, Ferry, Franklin, Garfield, Grant, Grays Harbor, Island, Jefferson, King, Kitsap, Kittitas, Klickitat, Lewis, Lincoln, Mason, Okanogan, Pacific, Pend Oreille, Pierce, San Juan, Skagit, Skamania, Snohomish, Spokane, Stevens, Thurston, Walla Walla, Whatcom, and Yakima. Twenty-four deaths; $140 million (est.) in insured losses; 250,000 people lost power. There were more than 130 landslides between Seattle and Everett, primarily along shorelines. Interstate 90 at Snoqualmie Pass was closed due to avalanche.

May 31, 1997 – Tornado Outbreak[219, 220] - A record six tornados touched down in Washington in one day; the state's previous record was four tornados in 1989 for the entire year. Four F1 tornados hit Stevens and Spokane counties in northeast Washington. Two F0 tornados touched down in western Washington – Vancouver and Tacoma. Also, on the same day in Idaho, an F1 tornado struck Athol and an F0 was observed near Lewiston. In addition, this storm produced severe thunderstorms with large hail up to two to three inches in diameter, heavy rain, and flash flooding, and wind gusts to near 80 mph. An F0 tornado has winds of 40-72 miles per hour and is capable of light damage. An F1 tornado has winds of 73-112 mph and is capable of moderate damage. No deaths or injuries reported. A record 14 tornados were reported in the state in 1997.

December 14-15 2006 Windstorm. Federal Disaster # 1682. The powerful windstorm slammed into Washington State with 90 MPH winds on the Coast, gusts up to 70 MPH in the Puget Sound basin, and peak winds well over 100 MPH along the Cascade Crest. Up to 1.5 million residents were without power for up to 11 days. The storm resulted in 15 deaths (including 8 from carbon monoxide poisoning). Governor Gregoire proclaimed an emergency for all 39 Counties. Total damages exceeded $50 million dollars.

December 1-17 2007 Severe Storm. Federal Disaster # 1734. A major disaster declaration was issued for 10 counties for Individual Assistance and 12 counties for Public Assistance, the latter comprised of

Clallam, Grays Harbor, Jefferson, King, Kitsap, Lewis, Mason, Pacific, Skagit, Snohomish, Thurston and Wahkiakum counties.

During the time period December 1-3, 2007, three storms moved over the Pacific Northwest. December 1st marked the first in the series, producing heavy snow in the mountains and low-land snow throughout western Washington. Snow fall levels ranged from a trace to 1" in Seattle, to many areas away from Puget Sound receiving over 4". On December 2nd, the snow changed over to rain as temperatures increased, accompanied by strong winds. As a low pressure system moved over the Olympic Peninsula, wind gusts of over 80 mph were observed along much of the coast (Hoquiam 81, Destruction Island 93, Tatoosh Island 86) and over 40 mph inland (Olympia 44, Seattle 48, Bellingham 53).

During this same storm series, a windstorm packing hurricane force winds battered the coasts of Washington and Oregon during December 1-3, 2007. Winds with this storm were second only to that of the 1962 Columbus Day Storm with a recorded gust of 102 mph at Klipsan Beach on the Long Beach Peninsula. Another report of 146 mph was also received from a communication tower at an elevated site (~1500 feet) near radar ridge in Pacific County. These strong winds caused extensive power and communication outages that lasted up to 4 days. The longevity of the strong winds, lasting up to 36 hours made this storm very unique and was responsible for much of the damage. This storm also delivered significant wave heights (top 1/3 of wave heights) of 44 to 48 feet in the offshore waters before unmooring the buoys that were observing them.

The most significant of the three storms arrived December 3rd, with near record high temperatures (59°F for Seattle) and moist tropical air which led to record rainfall and flooding around western Washington. Reports indicated that 6-hour and 24-hour precipitation amounts were at or near 100-year rain frequency levels. For Sea-Tac Airport, December 3, 2007 became the 2nd wettest day on record with 3.77" (first is 4.93" recorded on October 20, 2003) and the wettest day on record for Bremerton which received 7.50" of rain, breaking the old record of 5.62" set December 10, 1921. Several sites reached all time record high river flows and set all-time record high flood stage levels, including the Chehalis River, which reached nearly 75 ft (10 feet over flood stage), breaking the previous record set in the floods of February 1996. The flooding of the Chehalis River led to widespread flooding throughout western Lewis County, including a stretch of I-5, forcing 20 miles of the interstate to be closed for 4 days. The Coast Guard rescued more than 300 people from the flood areas, and the flooding and mudslides resulted in at least 5 deaths.

January 6-8, 2009 Severe Winter Storms, Landslides, Mudslides, and Flooding - Federal Disaster No 1817[221]. A strong, warm, and very wet Pacific weather system brought copious amounts of rainfall to Washington during the period 6-8 January, 2009, with subsequent major flooding extending through January 11, 2009, as well as minor flooding that continued through most of January. The storm involved a strong westerly flow aloft with embedded sub-tropical moisture, known as an *atmospheric river* of moisture. Snow levels rose from near sea level to between 6,000 and 8,000 feet, with strong westerly winds enhancing precipitation amounts in the mountains. Antecedent conditions from a mid-December through early January region-wide cold snap and associated heavy snow helped set the stage for flooding. This event also produced avalanches in the mountains, and caused more than an estimated 1,500 land/mudslides across the state, and resulted in structural damage to buildings from added snow load, compounded by heavy rains.

All counties of Western Washington lowlands received 3-8 inches of rain, while east of the Cascades, amounts ranged from 2 to 7.5 inches. On January 7, 2009, Olympia set a daily record with 4.82 inches. The National Weather Service issued flood warnings for 49 flood warning points across the state. Some daily rainfall records were broken on January 7th at airports: Sea-Tac saw 2.29 inches that broke 1.33

inches on January 7th in 1996, Olympia saw 4.82 inches breaking 1.95 set on January 7, 2002, and Quileute saw 2.88 inches breaking 2.39 set on January 7, 1983.

Emergency Alert System was activated by NWS Seattle and Portland as 22 Western Washington rivers exceeded *major* flood category. Two rivers, the Naselle in Pacific County and the Snoqualmie reached all-time record crests. Six rivers had near-record crests, while Mud Mountain Dam and Howard Hanson Dam had record levels of inflows. The State's primary north-south rail line was also closed. Interstate-5 was closed from milepost 68 to 89 for 43 hours due to water over the roadway around Chehalis. The economic impact of this closure was estimated at $12 million per day. Public Assistance was provided to 22 counties, while Individual Assistance was provided to 15 counties.

January 11 – 21, 2011 Severe Winter Storm, Flooding, Landslide, and Mudslides. Federal Disaster #1963.[222]
According to NOAA's National Climatic Data Center, "A cold easterly wind through the Columbia River Gorge was keeping cold air trapped in the Gorge as a strong Pacific frontal system moved inland. This system spread precipitation over the Gorge starting as snow and changing over to freezing rain as the air mass warmed." This storm was marked largely by icing damages. Public Assistance was granted to King County, Kittitas County, Klickitat County, Lewis County, Skagit County, Skamania County, and Wahkiakum County. The Preliminary Damage Assessment report indicated nearly $8.7 million in damages. Countywide per capita impact (based on 2000 demographic data) was as follows: Countywide per capita impact: King County ($3.57), Kittitas County($20.30), Klickitat County ($8.19), Lewis County ($9.42), Skagit County ($6.85), Skamania County ($22.49), and Wahkiakum County ($21.71).

January 14 -24, 2012 Severe Winter Storm, Flooding, Landslide and Mudslides. Federal Disaster #4056.[223] This winter storm 'Snowmageddon' disrupted airport traffic, closed roads and schools, downed trees resulting in tons of debris blocking roads and knocked out power to more than 275,000 customers across the state. According to the National Climatic Data Center, "arctic air moved into the region followed by a series of moderate to strong upper level storm systems riding on a moist subtropical jet stream. The result was widespread heavy snow and local high winds." Damage estimates of over $32million were reported in the Preliminary Damage Assessment document.[224] Public Assistance was granted to 11 counties: Clallam, Grays Harbor, King, Klickitat, Lewis, Mason, Pierce, Skamania, Snohomish, Thurston, and Wahkiakum. The per capita damage estimates in each of these counties is as follows: Countywide per capita impact according to the Preliminary Damage Estimate is as follows: Clallam County ($3.57), Grays Harbor County ($7.21), King County ($3.97), Klickitat County ($113.46), Lewis County ($13.86), Mason County ($9.72), Pierce County ($12.87), Skamania County ($83.72), Snohomish County ($7.72), Thurston County ($13.00), and Wahkiakum County ($3.49) (based on 2000 demographic data). These damages resulted in a statewide per capita impact of $1.35. Over 800 recovery projects were applied for as a result of the storm.

July 20, 2012 Severe Storm, Straight-line Winds, Flooding. Federal Disaster #4083.[225] Public Assistance was made available to Ferry and Okanogan Counties and the Confederated Tribes of the Coleville Reservation. Damage was largely a result of fallen trees onto structures and power lines. This event was carried wind bursts exceeding 100 miles per hour that resulted in extensive property damage and power disruption. One fatality was reported in Ferry County and dozens of structures (including homes) were damaged.

According the National Climatic Data Center (NCDC), this was one of the most widespread severe weather events to occur across the Spokane County Warning area.[226] The details of the event from NCDC follow: A combination of afternoon heating and smaller impulses ejecting from the offshore low kept the region very unsettled with several rounds of severe thunderstorms from the 15th through the 19th. On the morning of the 20th, the remnants of Tropical Storm Fabio became ingested into the southerly flow and moved toward the region. Meanwhile, a shortwave dropping into the Gulf of Alaska acted to kick the upper-low off the southwestern Oregon Coast inland. The upper-level wave took on a strong negative tilt, driven northeastward by a 75 knot jet streak, crossing through Eastern Washington during the early to late afternoon on July 20th. The combination of strong dynamic forcing along the shortwave, presence of an abnormally moist, unstable air mass, time of day, highly diffluent flow aloft, and jet streak dynamics led to numerous severe thunderstorms across Eastern Washington. Severe hail, winds, and flash flooding were observed with storms during the early afternoon but the threat transitioned to severe winds by the mid to late afternoon as storms migrated into the Northeastern Mountains. These storms blew down hundreds of trees causing one fatality. Ferry and Okanogan Counties were the hardest hit counties and experienced power outages in some remote communities in excess of one week. Consequently, state and federal assistance was necessary.

Preliminary damage figures for Ferry County estimated $2.6 million in debris removal, $1.6 million in emergency protective measures, $128,000 for road and bridge repair, $570,000 to building and equipment, $3.2 million for utility repair, and $163,000 for parks and recreation. Seven thousand people lost power in Ferry County and three major roads were closed for sometime due to downed trees. These roads included Highways 21, 97, and 155. Utility companies estimated 200 downed power poles and 40 miles of line needed restoration. In Okanogan County, estimations of $82,000 in debris removal, $36,000 in emergency protective measures, $180,000 for road and bridge repair, $419,000 to building and equipment, $364,000 for utility repair, and $25,000 for parks and recreation. Cumulative figures indicated a total of $8.4 million for Ferry County and $1.1 million for Okanogan County. Some reports stated that private weather instruments at residents' houses recorded winds between 80 and 100 miles per hour.

Table 75 Summary of Impacts of Hazardous Weather in Washington State – 1995 to 2012230F[227]

Year	Fatalities	Injuries	Property Damage	Crop Damage	**FEMA Disaster Number**
1995	3	2	$10.3 million	not listed	
1996	13	34	$63.9 million	$5.7 million	**#1100, #1152, and #1159**
1997	26	21	$23.6 million	$900,000	
1998	4	15	$22.9 million	$85.4 million	
1999	6	15	$39.7 million	$300,000	
2000	3	21	$11.2 million	$100,000	
2001	11	19	$7.6 million	$95.5 million	
2002	5	12	$14.5 million	$90.3 million	
2003	4	37	$31.3 million	not listed	
2004	1	10	$6.4 million	$5.5 million	
2005	4	23	$14.5 million	$100.3 million	
2006	5	58	$171.7 million	$69.7 million	**#1682**
2007	15	19	$197.28 million	$20,000	**#1734**
2008	7	5	$31.78 million	$105 million	**#1817**
2009	4	4	$123.93 million	$10,000	
2010	2	8	$11 million	$90,000	
2011	6	5	$18.82 million	$680,000	
2012*	N/A	N/A	N/A	N/A	**#4056 #4083, and #1963**
Totals	119	308	$800.41 million	$559.5 million	

As of February 22, 2013, 2012 data from the National Weather Service was not available for inclusion in this edition. The NOAA National Climatic Data Center was also consulted for 2012 data. No deaths, injuries or property damage were reported for winter storms, high wind, or thunderstorm wind. *Severe storms that resulted in flooding are described in more detail in the Flood hazard profile

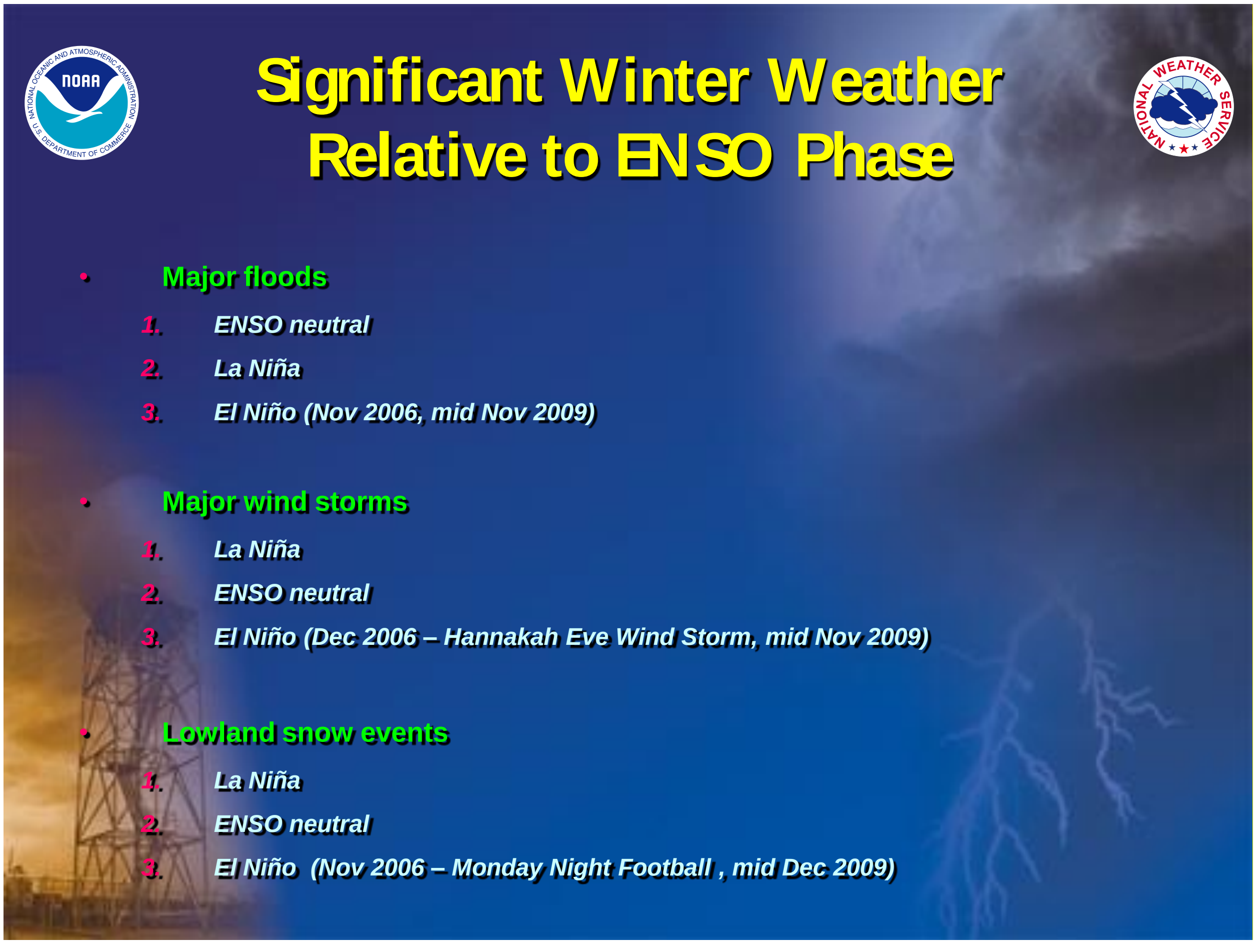
An associated event associated with winds the bears monitoring are dust storms. Several dust storms have occurred in recent years like the October 4, 2009 and May 3, 2010 events in eastern Washington captured by NASA Earth Observatory's Moderate Resolution Imaging Spectroradiometer (MODIS) available at http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=40590. In 2009, visibility dropped to zero in parts of eastern Washington as a large dust storm blew through. The storm brought strong winds gusting to 43 miles per hour in places that propelled the dust across the southeast corner of the state. After numerous multi-vehicle accidents, sections of Interstate 90 near the town of Moses Lake and several local roads had to be closed for several hours. Dryland farmers rely entirely on rainfall to sustain their crops, and as a result, do many things to preserve moisture in the soil. Some of these practices—leaving a field fallow after harvest to allow water to build in the soil for a year or covering the field with dry soil to prevent underlying moisture from evaporating—make dryland agriculture very prone to dust storms. These fields are likely either fallow or newly planted, probably with winter wheat, a common dryland crop in eastern Washington. The dust storm persisted for several hours. In 2010, the dust was rising from farmland in Central Washington where crops are not yet growing. The winds were blowing at 40 miles per hours. The winds blew the dust across the state, forcing several roads to close because of low visibility. No events have been reported since the 2010 event. However, continuing climate change may make Washington more vulnerable to dust storms.

Unrelated but still relevant is Space Weather because of its ability to disrupt radio communications networks including cellular systems, satellites, Global Positioning Systems (GPS), power grids, and aviation. Space weather comes in the form of radio blackouts, solar radiation storms, and geomagnetic storms caused by solar disturbances from the Sun. Alone, space weather can be a nuisance but combined with an evolving disaster event, it could significantly impact response and recovery efforts. Currently, NOAA National Weather Service Space Weather Prediction Center provides watches, alerts and warnings, plus educational tools at http://www.swpc.noaa.gov/.

Probability of Future Events

Based on a Ted Buehner, Warning Coordination Meteorologist, National Weather Service, Seattle Forecast Office, presentation to Washington State Emergency Management on October 25, 2012 using National Climate Prediction Center forecasts and his personal experience as a meteorologist in the northwest, severe storms can occur in any given winter regardless of the El Nino Southern Oscillation (ENSO) phase. However, some general trends can be teased out as depicted in the presentation slide below (Figure 5.7-5) as to the frequency of the event type to the ENSO phase. Otherwise, climate predictions are limited to 30 days and weather forecasts are limited to 7-10 days. Severe storms and their associated wind, snow and flooding effects will occur in Washington State regularly.

Figure 76 El Nino Southern Oscillation (ENSO) phase


Significant Winter Weather
Relative to ENSO Phase
• Major floods
1. ENSO neutral
2. La Niña
3. El Niño (Nov 2006, mid Nov 2009)
• Major wind storms
1. La Niña
2. ENSO neutral
3. El Niño (Dec 2006 – Hannakah Eve Wind Storm, mid Nov 2009)
• Lowland snow events
1. La Niña
2. ENSO neutral
3. El Niño (Nov 2006 – Monday Night Football , mid Dec 2009)

Jurisdictions Most Vulnerable to Severe Storms

For the State Hazard Mitigation Plan, factors used to determine which counties are most vulnerable to a future non-flood, severe storm are:

- Counties most vulnerable to the non-flood meteorological criteria below, as determined by the Warning Coordination Meteorologist s from the National Weather Service whose offices oversee areas within Washington State.[228]
- How often severe storm events occur, expressed as a percentage of recurrence per year. The percentage used to differentiate jurisdictions most vulnerable differs by storm type and is explained below.

Data for frequency of severe storm events was obtained from the Special Hazard Events and Losses Database for the United States (SHELDUS, beta version), developed by the Hazard Research Lab at the University of South Carolina, and from the National Climatic Data Center of the National Oceanic and Atmospheric Administration. SHELDUS uses a variety of NOAA data sources. It covers severe weather events from 1960 through 2009 that caused more than $50,000 in property and/or crop damage. Data obtained from the National Climatic Data Center covered weather events causing more than $100,000 in property and/or crop damage from 1993 through 2012 (except June and July 1993, for which data is not available), with the following exceptions: Tornado information is from 1950 to 1992 and Thunderstorm wind and hail information is from 1955 to 1992. Analysis of the data sets eliminated duplicate entries between the SHELDUS and National Climatic Data Center data.

Figure 77 shows the hazard losses from 1960 to 2009.

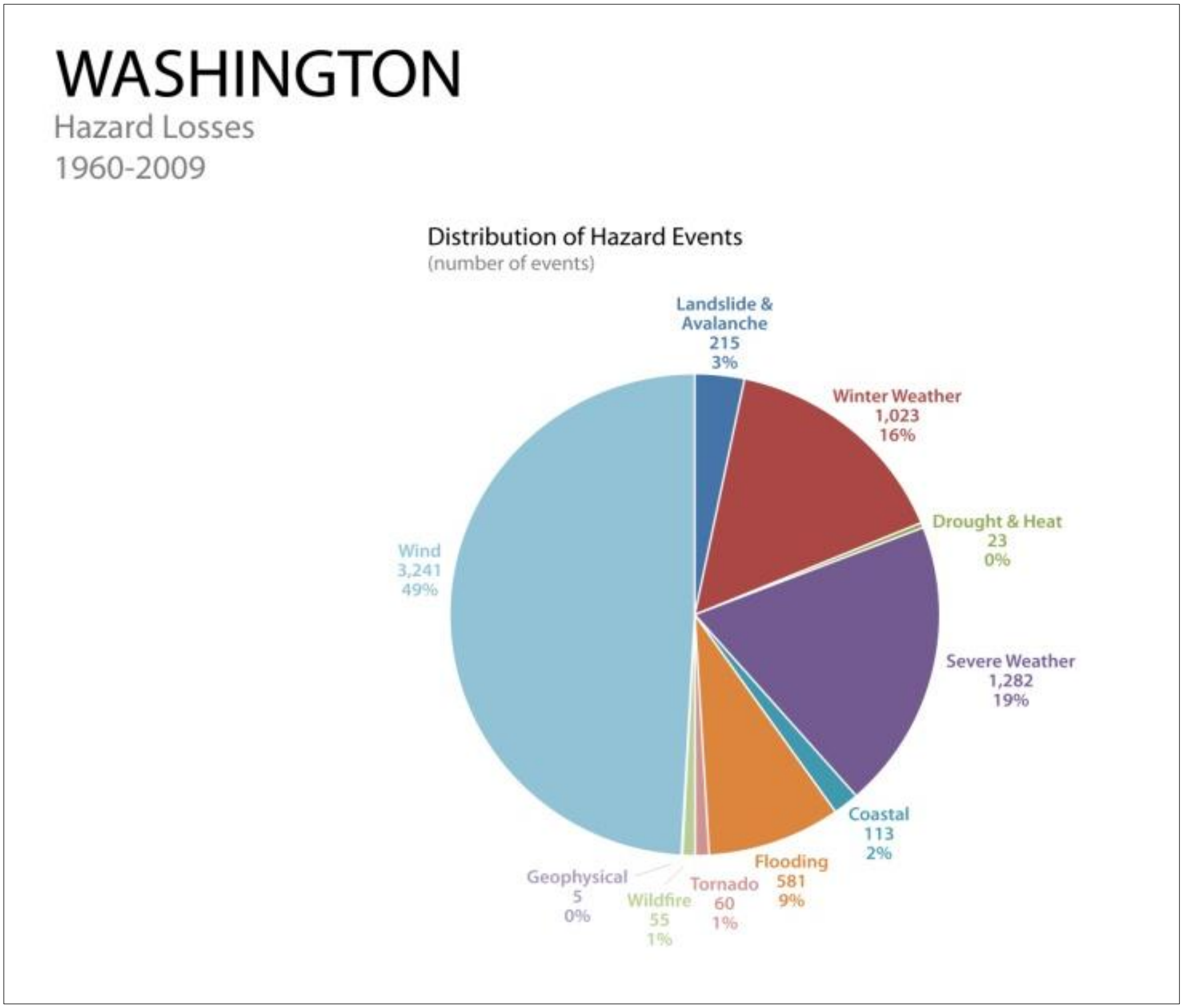
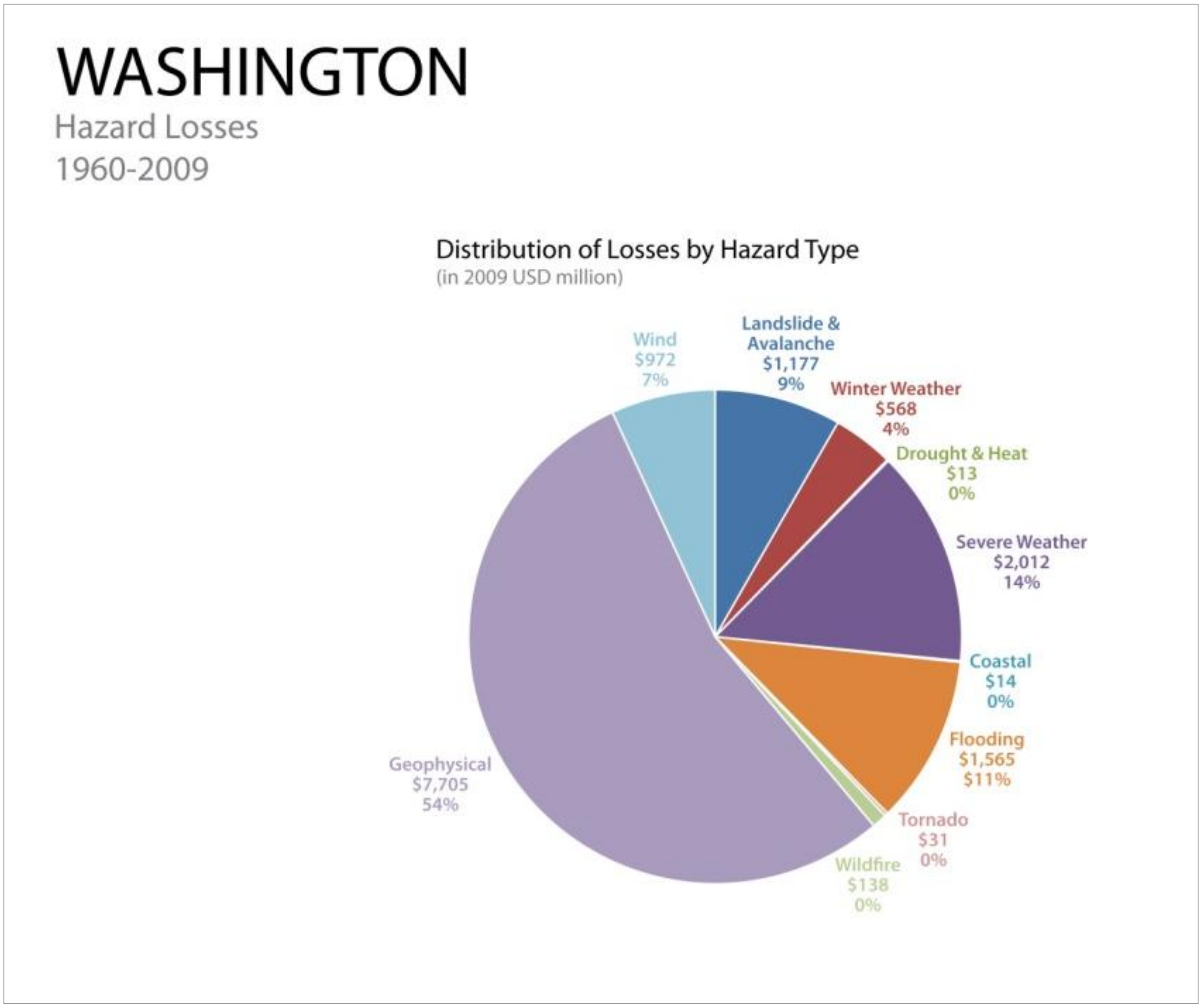


Figure 78 shows the losses by hazard type from 1960 to 2009



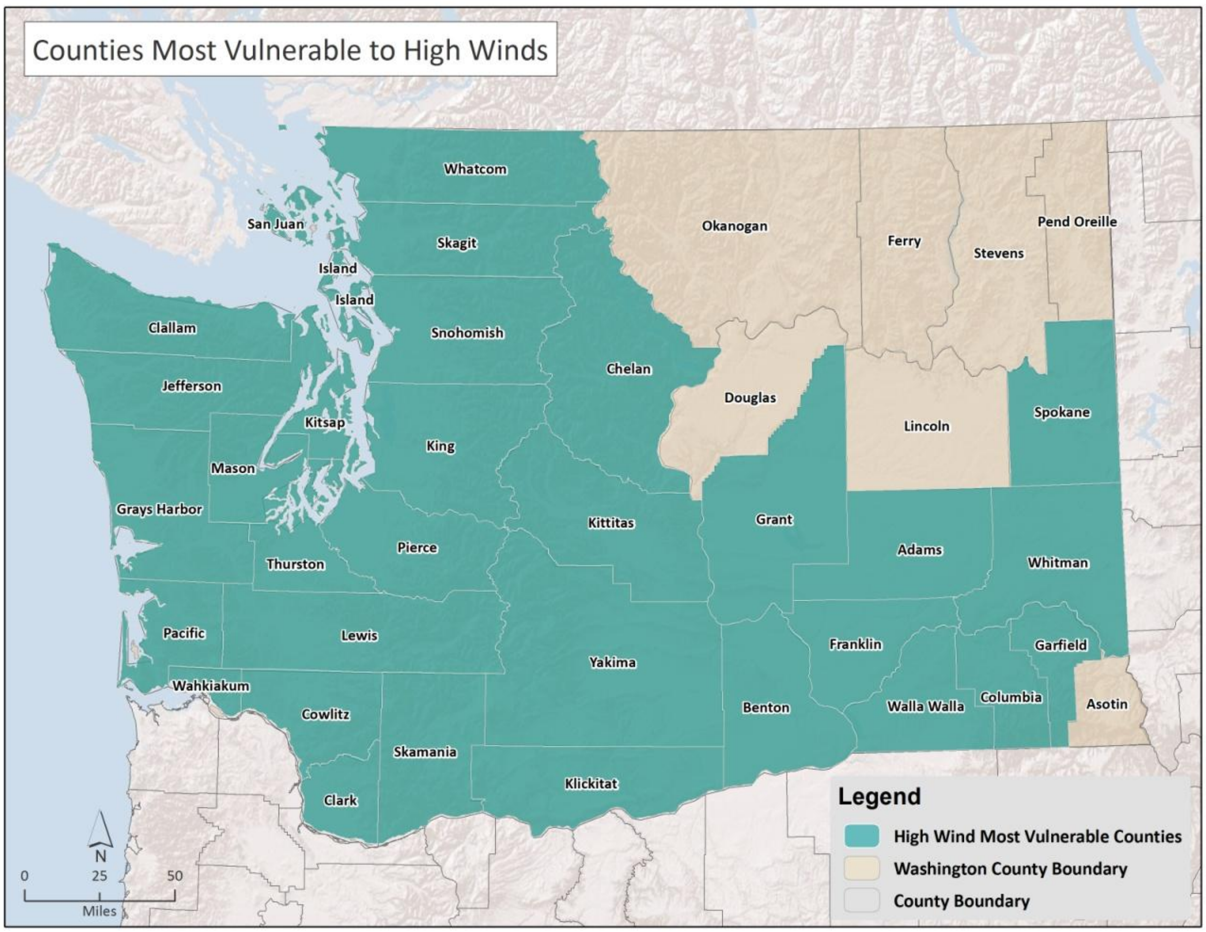
Source: SHELDUS (http://webra.cas.sc.edu/hvri/products/sheldusmaps.aspx)

The severe storm events for each county's vulnerability include high winds and winter storm history.

High winds – The National Weather Service defines high winds as sustained winds of 40 mph or gusts of 58 mph or greater, not caused by thunderstorms, expected to last for an hour or more. Areas most vulnerable to high winds are those affected by a strong pressure difference from deep storms originating over the Pacific Ocean; an outbreak of very cold, Arctic air originating over Canada; or strong air pressure differences between western and eastern Washington that primarily affect the Columbia River Gorge, Cascade Mountain passes, ridges and east slopes, and portions of the Columbia Basin.

Counties considered most vulnerable to high winds are 1) those most affected by conditions that lead to high winds, as described above, **and** 2) those with a high wind recurrence rate of 100 percent, meaning the county experiences at least one damaging high wind event every year. Several counties were added to the most vulnerable list for the 2013 plan update. These include Klickitat (strong east wind Gorge events), and many counties east of the Cascades such as Franklin, Grant, Adams, Whitman, and Garfield. Counties that meet both criteria, or were recommended for inclusion by the Warning Coordination Meteorologists for the National Weather Service, are highlighted in Figure 79 and in Table 76, below.

Figure 79 Counties Most Vulnerable to High Winds



Winter storm – The National Weather Service defines a winter storm as having significant snowfall, ice, and/or freezing rain; the quantity of precipitation varies by elevation. Heavy snowfall is 4 inches or more in a 12-hour period, or 6 inches or more in a 24-hour period in non-mountainous areas; and 12 inches or more in a 12-hour period or 18 inches or more in a 24-hour period in mountainous areas.

Areas most vulnerable to winter storms are those affected by convergence of dry, cold air from the interior of the North American continent, and warm, moist air off the Pacific Ocean. Typically, significant winter storms occur during the transition between cold and warm periods.

Counties considered most vulnerable to winter storm are 1) those most affected by conditions that lead to such storms, as described above, and 2) those with a recurrence rate of 50 percent, meaning the county experiences at least one damaging winter storm event every two years. Several Counties were added during the 2013 plan update. These include Whatcom (very vulnerable given the proximity to the Fraser river canyon 'nor'easters'), Skagit, San Juan, Lewis, and Kitsap Counties. Counties that meet both criteria, or were recommended for inclusion by the Warning Coordination Meteorologists for the National Weather Service, are highlighted in Figure 80 and in Table 75, below.

Nonetheless, because of Washington State's location on the windward coast of the Northern Pacific Ocean, along with its mountainous topography, which influences precipitation patterns, Washington State is assured of powerful severe storm events in the future. With the risk of severe storms impacting many Washington counties with significant populations, personal preparedness along with city and local preparedness planning for severe storm events may be able lessen the impact to individuals and local jurisdictions when the next severe storm occurs.

Figure 80 Counties Most Vulnerable to Winter Storms

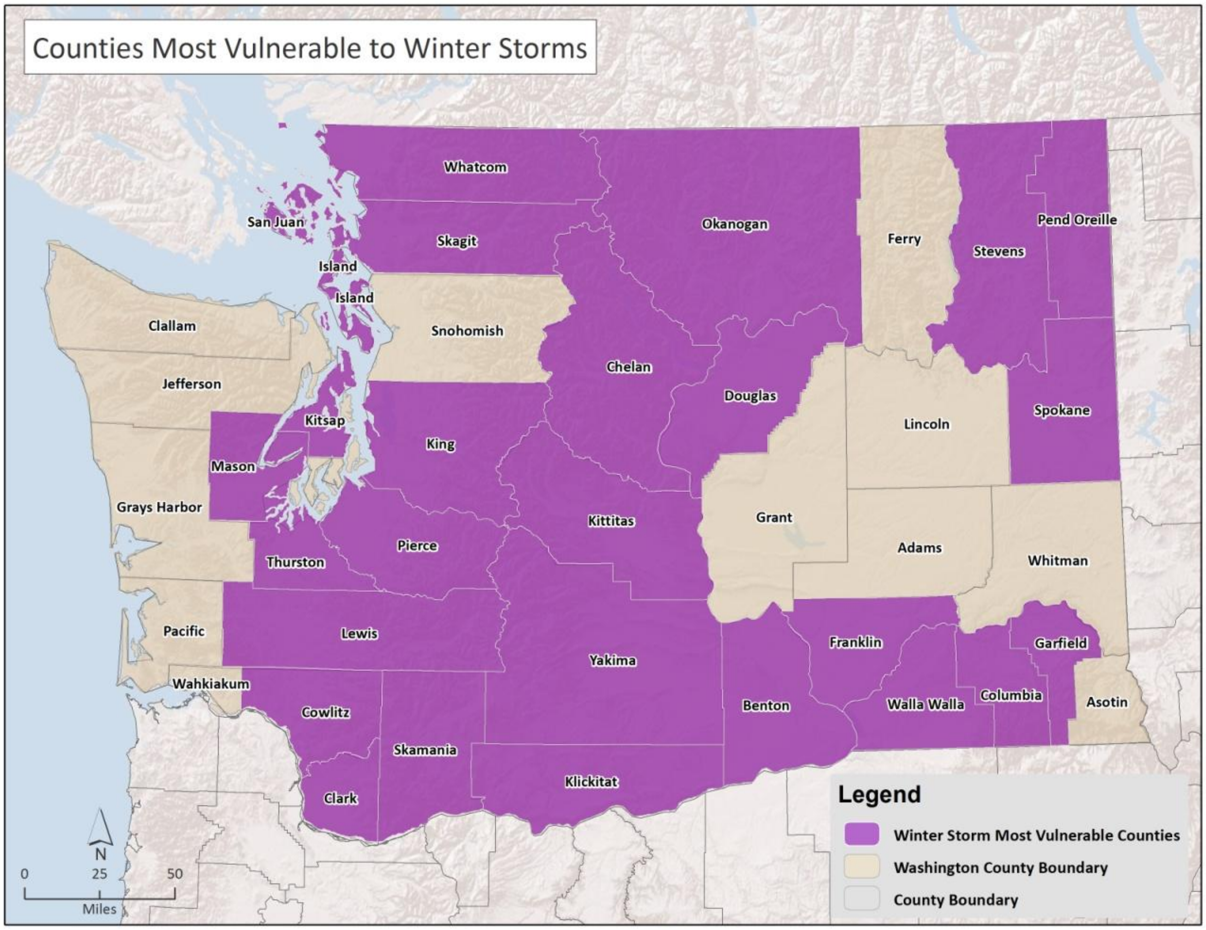


Table 76	Counties Most Vulnerable to High Winds (shade indicates most vulnerable)		Counties Most Vulnerable to Winter Storm (shade indicates most vulnerable)	
Counties (shaded for most vulnerable)	Vulnerable to Meteorological Conditions	Recurrence Rate (>100% – At least 1 occurrence per year)	Vulnerable to Meteorological Conditions	Recurrence Chance / Year (>50% – At least one occurrence every two years)
Adams	YES	70%, Included by NWS	NO	35%
Asotin	NO	70%	YES	23%
Benton	YES	140%	NO	48%
Chelan	YES, East Slopes of Cascades	Included by NWS	YES	Included by NWS
Clallam	YES, Pacific Coast	118%	YES	48%
Clark	YES	130%	YES, East County	85%
Columbia	YES	120%	YES	38%
Cowlitz	YES	113%	YES	60%
Douglas	NO	80%	YES	143%

Ferry	YES, Higher Elevations	65%	YES	23%
Franklin	YES	80%, Included by NWS	NO	33%
Garfield	YES	70% Included by NWS,	YES	73%
Grant	YES	93%, Included by NWS	NO	60%
Grays Harbor	YES	170%	NO	40%
Island	YES	148%	NO	43%
Jefferson	YES, Pacific Coast	125%	YES	43%
King	YES	133%	YES	70%
Kitsap	YES	125%	YES	35%, Included by NWS
Kittitas	YES	110%	YES	110%
Klickitat	YES	73%, Included by NWS	YES	38%
Lewis	YES	123%	YES	33% Included by NWS,
Lincoln	YES	75%	YES	25%
Mason	YES	165%	YES	60%
Okanogan	YES	83%	YES	128%
Pacific	YES, Pacific Coast	213%	NO	33%
Pend Oreille	YES	73%	YES	Included by NWS
Pierce	YES	165%	YES	60%
San Juan	YES, Western Half	173%	YES	48%, Included by NWS
Skagit	YES	188%	YES	58%, Included by NWS
Skamania	YES	95%	YES	88%
Snohomish	YES, Western Half	175%	YES	58%
Spokane	YES	105%	YES	55%
Stevens	YES, Higher Elevations	83%	YES	Included by NWS
Thurston	YES	175%	YES	50%
Wahkiakum	YES	118%	NO	35%
Walla Walla	YES	90%	YES	98%
Whatcom	YES, Western Half	190%	YES	65%, Included by NWS
Whitman	YES	93%, Included by NWS	YES	30%
Yakima	YES	103%	YES	73%

Potential Climate Change Impacts [229] [230,231, 232,233,234,] [235]

With weather patterns drawing much of their dependence and rate of occurrences on the climate of a given area, it is only fitting to address the impacts that global climate change may have to severe weather incidents. According to climate models done by the University of Washington's Climate Impacts Group, the rate of temperature change will increase in the Pacific Northwest as will the amount of temperature change. They predict an average rate of warming of 5 degrees Fahrenheit per decade through 2050 and an average annual temperature increase of 2 degrees Fahrenheit. Seasons on average will all be warmer than previously experienced and the average annual temperature will likely exceed the range of the 20th century variability in the next 30 years in the Pacific Northwest. Precipitation in the Pacific Northwest is expected to increase by 1 to 2%, with more than half of the climate models projecting this increase in the winter (December-February) months and a large percentage of this precipitation will fall as rain rather than snow due to warmer winter temperatures.

Changes in the behavior of climate patterns such as El Niño and La Niña that effect storms in Washington are not well modeled. Thus, there is insufficient information in order to make a prediction as to how climate change will affect these sources of inter-annual climate variability in the Pacific Northwest. While severe storms have impacted every corner and jurisdiction in the State, counties at most risk of a future severe storm event include those counties along the Pacific Ocean, counties located within the Puget Sound basin, counties along the eastern slopes of the Cascade Mountains, and the southeastern counties of Benton, Walla Walla, and Columbia counties, as well as Spokane County.

Vulnerability to severe storm hazards is a function of location, type of human activity, use, and frequency of storm events. The effects of severe storms on people and structures can be lessened by total avoidance of flood hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity. Local governments can reduce flooding, landslides and wind effects through land-use policies and regulations. Individuals can reduce their exposure to hazards by educating themselves on the past history of a site and by making inquiries to planning and engineering departments of local governments. In addition, it is highly advised to consult the professional services of an engineering geologist, geotechnical engineer, or a civil engineer, who can properly evaluate a site, built or un-built.

Coastal flooding is also a concern in Washington with the rise in sea level because of global ocean warming. As global temperature rise, oceans expand and ice melts, causing the water level to rise. The State of Washington has over 3,000 miles of marine coastline. The United Nation's Intergovernmental Panel on Climate Change (IPCC) reports that from 1993 to 2003, global sea level rose about 3 millimeters (approximately 0.12 inches) each year, and approximately half of that increase is attributed to the ocean expanding as it warms. While a sea rise of a few millimeters may seem insignificant, Carol Auer, an Oceanographer with the National Oceanic and Atmospheric Administration (NOAA) says, "A half-inch of vertical sea level rise translates to about three feet of land lost on a sandy open coast, due to long term erosion. Moreover, even a slightly higher sea level can cause more dramatic deltas and estuary tides. Rising sea levels also make coastal areas more vulnerable to storm surges, and in turn, to flooding".

The State of Washington Department of Ecology addresses Sea Level Rise as well. They cite a 2012 National Research Council report titled *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past Present and Future. The report predicts a 24 inch rise for the West Coast by 2100, with a range of 4 to 56 inches.* Essentially, more land and thus people and structures are vulnerable to the hazard. The Department of Ecology has also laid out a strategy to reduce losses and determine risk to the hazard.

According to a 2005 Governor's report prepared by the Climate Impacts Group titled *Uncertain Future: Climate Change and its Effects on Puget Sound*, from "paleoclimatological evidence, we know that over the history of the earth high levels of greenhouse gas concentrations have correlated with, and to a large extent caused, significant warming to occur, with impacts generated on a global scale." While the report also indicates that the "ultimate impact of climate change on any individual species or ecosystem cannot be predicted with precision," there is no doubt that Washington's climate has demonstrated change.

In July 2007, the Climate Impacts Group launched an unprecedented assessment of climate change impacts on Washington State. *The Washington Climate Change Impacts Assessment* (WACCIA) involved developing updated climate change scenarios for Washington State and using these scenarios to assess the impacts of climate change on the following sectors: agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon, and urban stormwater infrastructure. The assessment was funded by the Washington State Legislature through House Bill 1303.

In 2009, the Washington State Legislature approved the *State Agency Climate Leadership Act* Senate Bill 5560. The Act committed state agencies to lead by example in reducing their greenhouse gas (GHG) emissions to: 15 percent below 2005 levels by 2020; 36 percent below 2005 by 2035; and 57.5 percent below 2005 levels (or 70 percent below the expected state government emissions that year, whichever amount is greater.). The Act, codified in RCW 70.235.050-070, directed agencies to annually measure their greenhouse gas emissions, estimate future emissions, track actions taken to reduce emissions, and develop a strategy to meet the reduction targets. Starting in 2012 and every two years thereafter, each state agency is required to report to Washington State Department of Ecology the actions taken to meet the emission reduction targets under the strategy for the preceding biennium.

Recognizing Washington's vulnerability to climate impacts, the Legislature and Governor Chris Gregoire directed state agencies to develop an integrated climate change response strategy to help state, tribal, and local governments, public and private organizations, businesses, and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy*.

Over the next 50 - 100 years, the potential exists for significant climate change impacts on Washington's coastal communities, forests, fisheries, agriculture, human health, and natural disasters. These impacts could potentially include increased annual temperatures, rising sea level, increased sea surface temperatures, more intense storms, and changes in precipitation patterns. Therefore, climate change has the potential to impact the occurrence and intensity of natural disasters, potentially leading to additional loss of life and significant economic losses. Recognizing the global, regional, and local implications of climate change, Washington State has shown great leadership in addressing mitigation through the reduction of greenhouse gases.

Some suggest that there is a better way to deal with floods: the "soft path" to flood risk management. The "soft path" strategy to flood management takes into account the fact that floods will happen and to learn to deal with them the best way possible. This strategy is also based on an understanding that flooding is essential for the health of riverine ecosystems. A "soft path" approach means taking measures to reduce the speed, size, and duration of floods by restoring meanders and wetlands…." This approach "also means doing all we can to get out of floods' destructive path with improved warning and evacuation measures. Such practices are already in use in some parts of the United States and around the world. Improving our ability to cope with floods requires adopting a more sophisticated set of techniques. The "soft path" of flood management should be a core part of efforts to adapt to a changing climate. Such a strategy may reduce deaths due to flooding and could result in much healthier rivers and streams. This philosophy can be expanded to include the other effects of severe storms.

At Risk State Facilities

This profile will not attempt to estimate potential losses to state facilities due to severe storm. The state does not have data on which to base a determination of which facilities might be most vulnerable to either high winds or winter storm events. However, all facilities are considered vulnerable to this hazard.

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Tsunami

	Frequency	50+ yrs	10-50 yrs	1-10 yrs	Annually
	People	<1,000	1,000-10,000	10,000-50,000	50,000+
	Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
	Environment	<10%	10-15%	15%-20%	20%+
	Property	<$100M	$100M-$500M	$500M-$1B	$1B+
TSUNAMI	**Hazard scale**		< Low to High >		

Risk Level[236]

Frequency – Based on geologic evidence along the coast of Washington State, the Cascadia Subduction Zone (CSZ) has ruptured and created tsunamis at least 7 times in the past 3,500 years. The last CSZ-related earthquake is believed to have occurred in 1700 and researchers predict a 10 - 14% chance that another one could occur in the next 50 years.

People – The tsunami inundation zone along the coast of Washington State contains more than 42,000 residents that could potentially be affected were a tsunami to occur.

Economy – The tsunami-inundation zone contains 2,908 businesses representing 31% of the businesses located in the four coastal counties of Washington State most prone to the effects of a Cascadia Subduction Zone generated tsunami. If a tsunami were to occur, the economic impact to these four counties could be severe and the State's economy would also be impacted.

Environment – The potential impact to the environment due to a tsunami does not meet the minimum threshold of ten percent or more loss of a single species or habitat.

Property – A USGS study on the vulnerability of Washington communities found that 18,397 households are in the tsunami-inundation zone along the coast of Washington. Property damage to these homes could be between $100 and $500 million dollars depending on the severity of the tsunami.

HIVA Risk Classification for Tsunami is 2D or Mitigation to Reduce Risk is Optional.

Hazard Area Map[237]

The tsunami inundation areas indicated on the map (Figure 81) were derived from 25-foot contour lines. This height of 25 feet was determined to be a plausible wave height for a coastal or Puget Sound located tsunami to be able to reach and cause flooding and other types of damage. Current research is beginning to use a 30 foot wave height. The Cascadia Subduction Zone is a region "where an oceanic tectonic plate (the Juan de Fuca plate) is being pulled and driven (i.e. subducted) beneath a continental plate (the North American plate). Earthquakes along the fault that is the contact between the two plates, termed the interpolate thrust or megathrust, may generate significant local tsunamis in the Pacific Northwest".

While tsunamis can occur in the Puget Sound, it is thought only to be a possibility if an earthquake is centered in this region and results in a tsunami. A coastal tsunami is not thought to be able to reach the Puget Sound area as the waves have many obstacles prior to reaching this region.

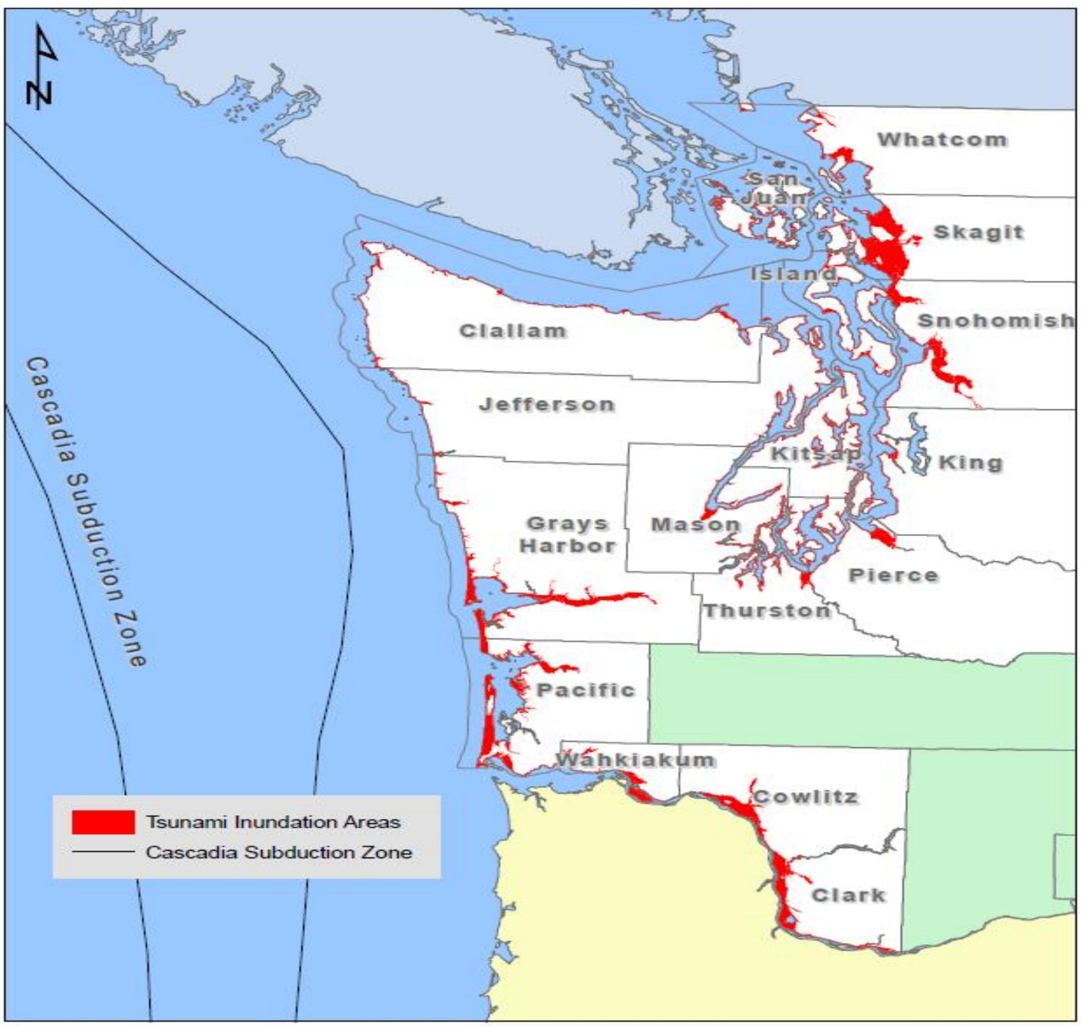


Figure 81 Tsunami Inundation Map for Washington State

Summary[238]

The hazard – A tsunami is a series of waves typically generated during an earthquake by sudden displacement of the sea floor or lake bed. Tsunamis are particularly dangerous close to their sources, where the first wave in the tsunami series can arrive less than an hour after the tsunami begins and where the earthquake has already created havoc.

Previous occurrences –Washington State has a long history of tsunamis from sources near and far. The largest of the nearby sources, the Cascadia Subduction Zone, produced its most recent great tsunami in 1700 AD. The State's tsunamis also include a Puget Sound tsunami from the Seattle Fault between 900 AD and 930 AD, a Tacoma Narrows tsunami from a landslide in 1949, a fatal wave from a rockfall into the Columbia River in 1965. The recent State's Pacific Ocean tsunamis include Aleutian Islands in1946, Chile in 1960, and Alaska in 1964. The 2011 Japanese tsunami debris has reached Washington State beaches in 2012.

Probability of future events –Tsunamis generated elsewhere on the Pacific Rim are the ones that strike Washington most often. The Washington portion of the Cascadia Subduction Zone produces a great earthquake (magnitude 8 or 9) and associated tsunami often enough for the next of these to have a one-in-ten chance, or better, of occurring in the next fifty years. The frequency of tsunamis from inland sources has not been determined.

Jurisdictions at greatest risk – Communities along the Pacific Coast and Strait of Juan de Fuca, including a number of coastal Indian tribes, are at greatest risk. In a Cascadia Subduction Zone earthquake, the level of the coast could fall or subside six feet, and tsunami waves could reach 30 feet, overtopping several low-lying coastal communities. The at-risk population from a Cascadia-related tsunami is approximately 43,000 residents and 25,000 employees on the outer coast. This analysis excludes tourists and transient populations that could increase the number significantly. In a 2008 study of community exposure on the open-ocean coast of Washington to Cascadia-related tsunamis, the City of Aberdeen had the highest number of residents, employees, dependent-population facilities, public venues, and total parcel value in the tsunami-hazard zone.

Global Perspective – In its earthquake and tsunami potential, the Pacific Northwest rivals the source areas of the greatest tsunamis of the last 100 years: Chile, Alaska, and Sumatra. Like all these areas, Cascadia Subduction Zone has a track record of generating ocean-wide tsunamis from earthquakes as large as magnitude 9.

The Hazard [239, 240, 241]

Tsunamis are a series of waves that threaten people and property along shorelines of the Pacific Coast, Strait of Juan de Fuca, Puget Sound, and large lakes. Sudden raising or lowering of the sea floor or a lake bed during an earthquake typically generates a tsunami, although landslides and underwater volcanic eruptions also can generate them.

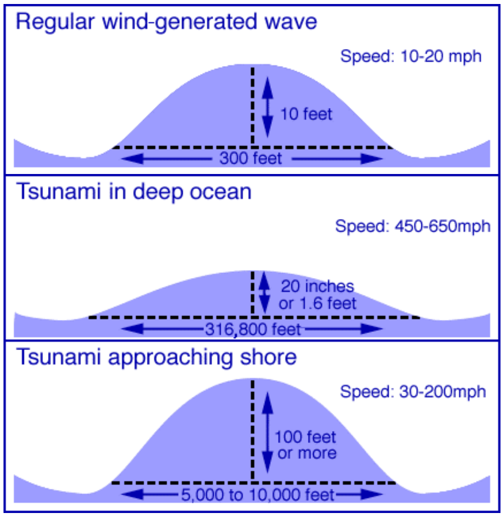


Figure 82 Wind-generated Waves vs. Tsunami Waves

Only as a tsunami approaches land does it become a hazard. In shallow water, it gains height as its waves slow and compress. Tsunamis can resemble a series of quickly rising tides, and they can withdraw with currents much like those of a river; they can also form breaking waves but these are less common than tsunami icons suggest. Swift currents commonly cause most of the damage from tsunamis. A Pacific Ocean tsunami can affect the entire Pacific basin, while a tsunami generated in inland waters can affect many miles of shoreline.

Tsunamis typically cause the most severe damage and casualties near their source. There, waves are highest because they have not yet lost much energy. The nearby coastal population, already reeling from the effects of an earthquake, may have little chance to flee before the tsunami arrives. Persons caught in the path of a tsunami often have little chance to survive; debris may crush them, or they may drown. Children and the elderly are particularly at risk, as they have less mobility, strength, and endurance.

A tsunami crosses the ocean at jetliner speeds, close to 600 miles per hour. The 1964 tsunami from Alaska's Aleutian Islands took less than five hours to reach Hawaii, where it killed 159 people. Computer simulations show that the January 26, 1700 tsunami from the Cascadia Subduction Zone along the Pacific Coast of Washington took about 10 hours to reach Japan, where it caused flooding and damage along 600 miles of the Pacific coast of Honshu.

Tsunami waves in the ocean can continue for hours; later waves can be larger, more deadly, and more damaging. For example, the first wave to strike Crescent City, CA, following the 1964 Alaska earthquake was 9 feet above the tide level; the second was 6 feet above tide; the third was about 11 feet above the tide level; and the fourth, most damaging wave was more than 16 feet above the tide level. The third and fourth waves killed 11 people. Estimates of the damage range from $47 million to $97 million (2004 dollars). The same tsunami destroyed property in many areas along the Pacific coast from Alaska to California. In Washington, the largest wave entered Willapa Bay about 12 hours after the first one; the tsunami caused $640,000 (2004 dollars) in damage (see Table 2, for wave heights along the Washington coast).

Although the 1964 event was the largest 20th-century tsunami on the Washington coast, the state has its own sources of tsunamis, and these have produced great waves recorded geologically in the last few thousand years.

Table 76. Recent Subduction Zone Earthquakes and Tsunamis Worldwide, 1946 – January 2013

Date	Origin	Effects	Casualties
April 1, 1946245F[242]	Aleutian Islands EQ Magnitude 8.6	Tsunami destroyed the Scotch Cap Lighthouse on Unimak Island, AK. Led to creation of The Pacific Tsunami Warning Center.	**165 dead in Alaska and Hawaii**
May 22, 1960246F[243]	South-Central Chile EQ Magnitude 9.5	Largest earthquake in world. Damage to Chile, Hawaii (61 tsunami deaths), and Japan (118 tsunami deaths).	**4,000-5,000 dead; 3,000 homeless; 2 million injured.**
March 27, 1964247F[244]	Prince William Sound, Alaska EQ Magnitude 9.2	Second-largest earthquake in 20th century. Shaking lasted 3 minutes. Severe damage to south coast of Alaska. Wave height at Valdez Inlet estimated at 220 feet. Tsunami deaths in AK, OR, Crescent City, CA.	**125 dead (tsunami 110, EQ 15)**
Aug. 23, 1976248F[245]	Celebes Sea EQ Magnitude 7.9	Southwest Philippines struck, devastating Alicia, Pagadian, Cotabato, and Davao.	**8,000 dead**
July 17, 1998249F[246]	Papua New Guinea EQ Magnitude 7.1	Arop, Warapu, Sissano, and Malol, Papua New Guinea devastated. Wave height estimated at 33 feet.	**2,200 dead; 200 missing; 9,500 homeless**
Dec. 26, 2004250F[247],251F[248]	Sumatra, Indonesia EQ Magnitude 9.0	Parts of Indonesia, Thailand, Malaysia, India, Sri Lanka, and Maldives devastated. Wave heights reached 100 feet. Tsunami measured around the world.	**283,000 dead; 14,100 missing; 1.1 million displaced**
March 28, 2005252F[249]	Sumatra, Indonesia EQ Magnitude 8.7	Parts of Sumatra Island, Indonesia badly damaged. Wave height estimated at 10 feet.	**1,400 dead**
September 29, 2009253F[250]	South Pacific Basin, Samoa EQ Magnitude 8.0	Parts of American Samoa, Western Samoa, and Tonga were severely impacted. Run-up of 56 feet was reported.	**160 dead, 7 missing**
March 11, 2011254F[251]	**Honshu, Japan EQ Magnitude 9.0**	**Near the East Coast of Honshu, Japan**	**20,896 dead**

Tsunami Threat in Washington[252]

Washington's outer coast faces a dual threat: tsunamis generated by distant sources such as earthquakes in Alaska, Chile, and Japan; and tsunamis generated directly offshore during an earthquake from the Cascadia Subduction Zone.

Just off the Washington State Pacific Ocean coast, the Cascadia Subduction Zone has generated magnitude 8 or larger earthquakes at least six times in the past 3,500 years. Each is known or suspected to have set off a tsunami. The most recent occurrence dates to the evening of January 26, 1700. During this earthquake and its predecessors, much of the land on Washington's outer coast subsided, or fell, by about five feet. Such lowering of the land makes coastal communities more susceptible to flooding and damage from the ensuing tsunami.

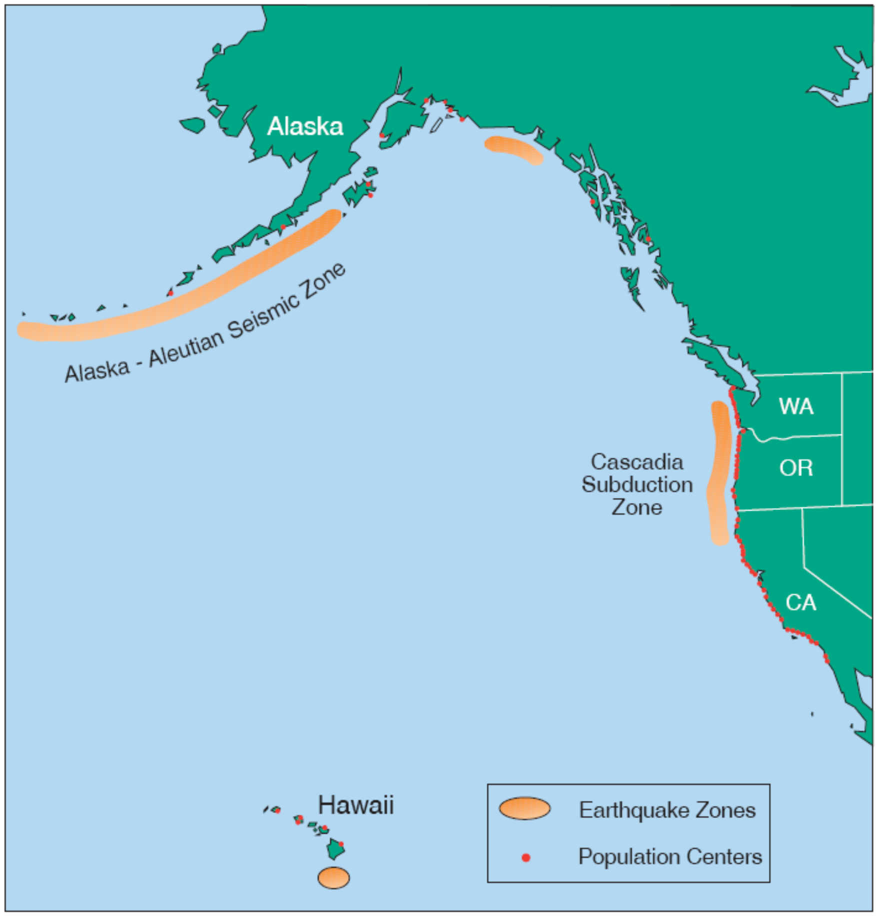


Figure 83 Tsunami Hazards for the West Coast of the United States

Computer models indicate that a Cascadia-generated tsunami could reach nearly 30 feet in height and affect the entire Washington coast. The first wave would reach coastal communities within 30 minutes after the earthquake, and reach communities along the Strait of Juan de Fuca in 90 minutes. Tsunamis from great Cascadia earthquakes probably account for several sand sheets on northwestern Whidbey Island and at Discovery Bay in Puget Sound.

Washington's Puget Sound waters also are subject to tsunamis. An earthquake around A.D. 900-930 on the Seattle Fault caused uplift that triggered a tsunami in central Puget Sound. A few days after the 1949 Olympia earthquake, a landslide into the Tacoma Narrows set off a tsunami.

As part of the U.S. National Tsunami Hazard Mitigation Program (NTHMP) the National Oceanic and Atmospheric Association (NOAA) set goals to: reduce the loss of life and property in U.S. coastal communities, reduce false alarms and the resulting high economic cost of unnecessary evacuations, lessen the physical risk to the population during evacuations, and reduce the loss of public confidence in the tsunami warning system. To achieve these goals NOAA developed deep-ocean tsunameters for early detection, measurement, and real-time reporting of tsunamis in the open ocean. The tsunameters were developed by Project DART (Deep-ocean Assessment and Reporting of Tsunamis) at NOAA's Pacific Marine Environmental Laboratory (PMEL) located in Seattle. The DART systems (Figure 4) have been deployed near regions with a history of tsunami generation to ensure measurement of the waves as they propagate towards threatened U.S. coastal communities and to acquire data critical to real-time forecasts.

Figure 84 The first DART (Deep-ocean Assessment and Reporting of Tsunami) Detection Buoy

This network now consists of a total of 39 deep-ocean detection and assessment buoys (Figure 85). "When a tsunami event occurs, the first information available about the source of the tsunami is based only on the available seismic information for the earthquake event. As the tsunami wave propagates across the ocean and successively reaches the DART systems (buoys), these systems report sea level information back to the Tsunami Warning Centers, where the information is processed to produce a new and more refined estimate of the tsunami source. The result is an increasingly accurate forecast of the tsunami that can be used to issue watches, advisories, warnings, or evacuations."[253]

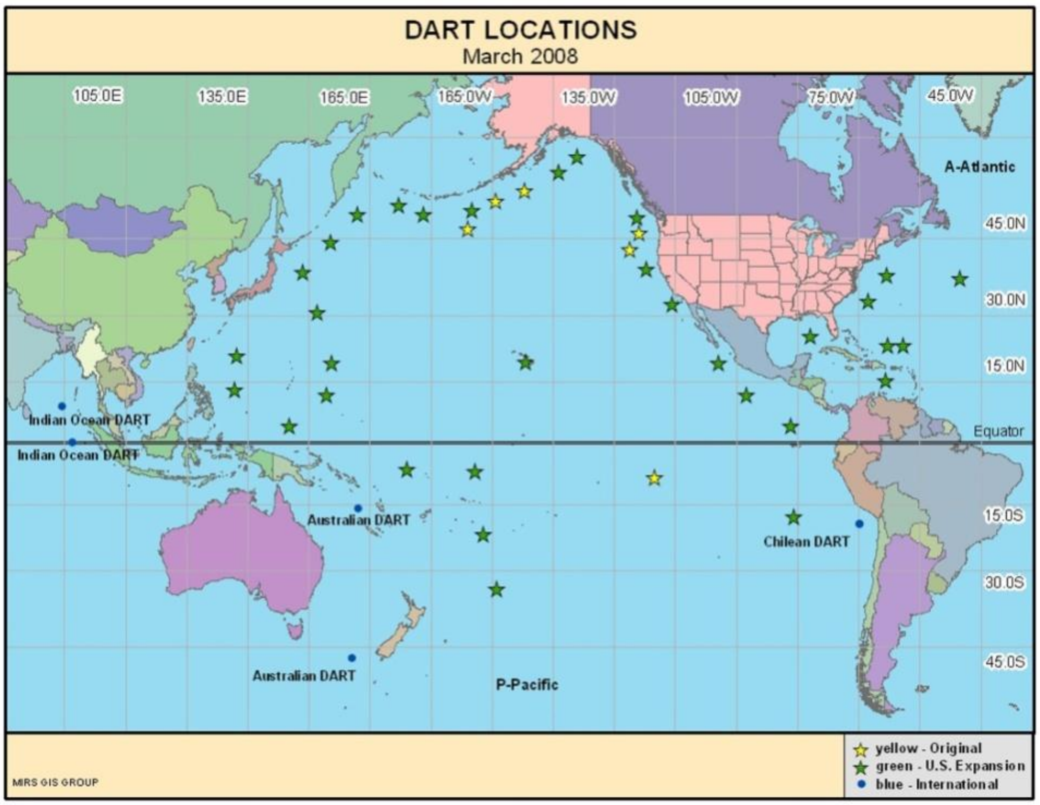


Figure 85 Location of NOAA DART (Deep-Ocean Assessment and Reporting) Tsunami Instruments, as of March 2008

Figure 86 Tsunami Evacuation and Hazard Zone Signs

This initiative toward recognizing tsunamis to issue warnings to affected communities has spread to educating communities on the tsunami potential, signs and signals a tsunami may be approaching, and measures to get out of harm's way should an event occur. Tsunami hazard zone signs are "intended to be posted at Pacific coast access points or other low-lying areas that would clearly be vulnerable to a large, locally generated tsunami." Tsunami evacuation route signs (Figure 6) are used to "designate that evacuation routes established by local jurisdictions in cooperation with emergency management officials."[254]

In addition to warning signs, NOAA's National Weather Service (NWS) has established a Tsunami Ready™ (Figure 7) program that "gives communities the skills and education to survive a tsunami before, during and after an event".[255] To meet criteria for this program communities must: establish a 24-hour warning point and emergency operations center, have more than one way to receive tsunami warnings and to alert the public, promote public readiness through community education and the distribution of information, and develop a formal tsunami plan, which include holding emergency exercises.

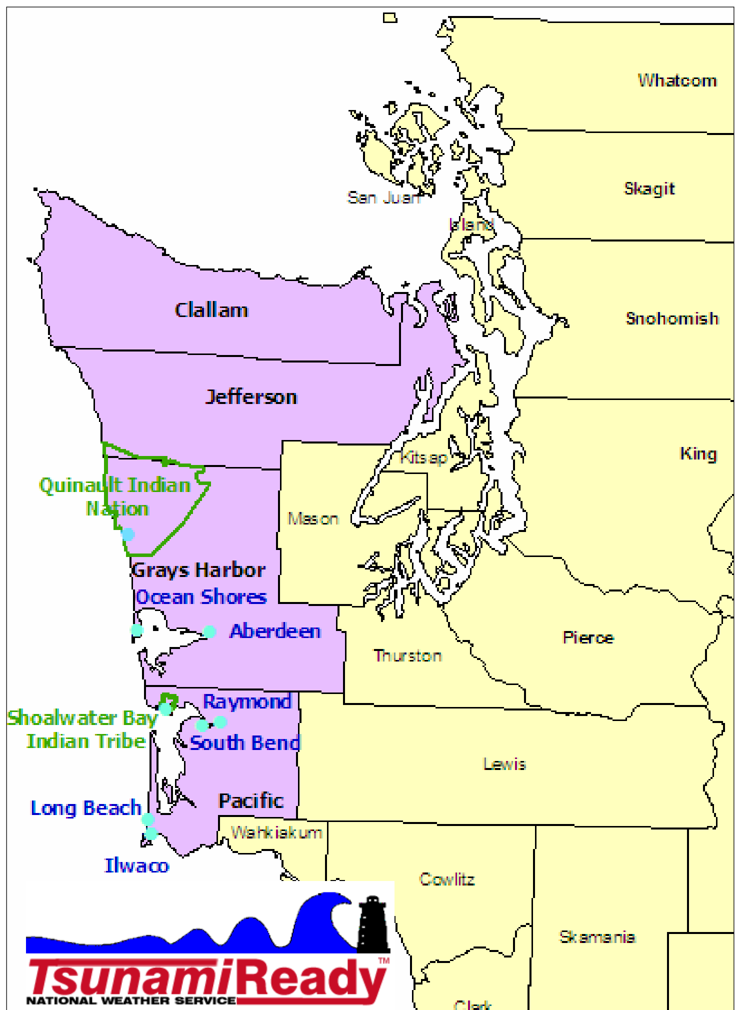


Figure 87 NOAA's National Weather Service TsunamiReady™

Currently, Washington State has 6 communities (Aberdeen, Ilwaco, Long Beach, Ocean Shores, Raymond and South Bend), 4 counties (Pacific, Grays Harbor, Jefferson, and Clallam), and 2 Indian Nation (Quinault Indian Nation and Shoalwater Bay Tribe) that have been granted the TsunamiReady™ status (Figure 8).

At least thirteen (13) of Washington State's Pacific Ocean coastal communities and tribal reservations lack natural high ground that is of sufficient elevation to escape a 30+ foot tsunami triggered by a Cascadia Subduction Zone earthquake. The lack of natural high ground coupled with preceding earthquake damage, close proximity to the fault (~50-100 miles), and limited time for evacuation (15-30 minutes) preclude the use of traditional horizontal or vehicular evacuation strategies. These limiting factors make 13 outer coastal communities in Washington extremely vulnerable to significant loss of life from such an incident. This situation is not unique to Washington State, as many low-lying coastal areas within U.S. states, commonwealths, and territories are also constrained by similar geographic factors.

To address this unique challenge, the concept of vertical evacuation was established. This evacuation strategy allows residents and visitors to move upwards to safety in man-made structures (buildings, towers, or berms) and is particularly important on peninsulas where traditional evacuation measures are not viable options for life safety. In 2008, FEMA collaborated with the National Oceanic and Atmospheric Association and published engineering guidance entitled "*Guidelines for Design of Structures for Vertical Evacuation from Tsunamis*" to promote the planning and development of life safety refuges in the United States (FEMA P646). In 2011, the vertical evacuation concept was tested to its fullest extent and successfully saved thousands of lives in Japan during the March 11, 2011 tsunami.

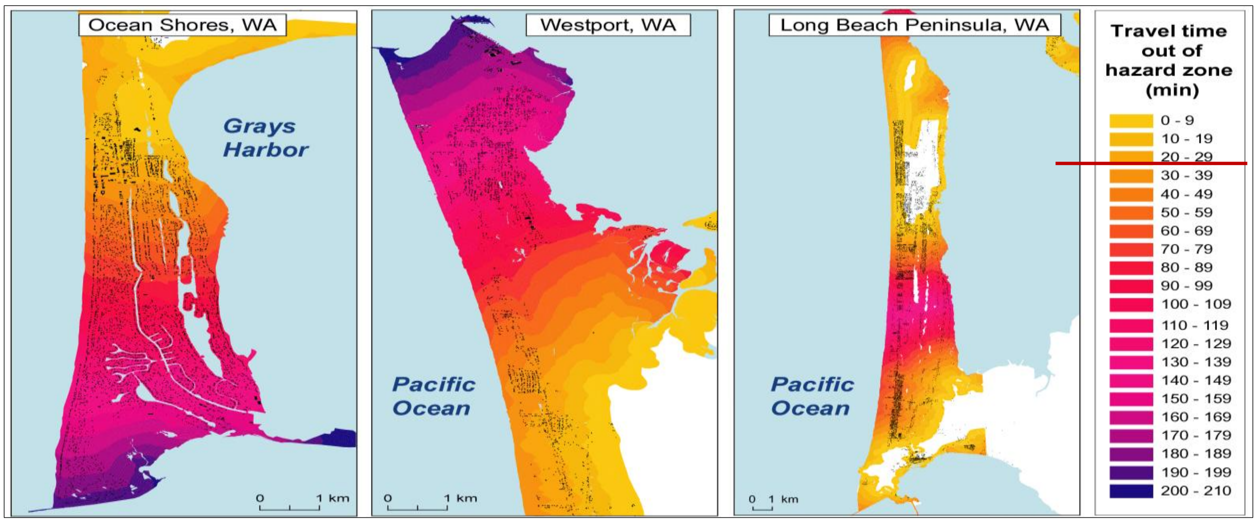


Figure 88 Modeled Tsunami Arrival Time
Source: Wood, N.; Schmidtlein, M.; and Schelling, J.; *Preparing for catastrophic tsunamis in the U.S. Pacific Northwest --- the use of pedestrian-evacuation modeling to target mitigation and education*; Paper #NH-38, American Geophysical Union (AGU) Science Policy Conference.

FEMA Post Disaster Mitigation (PDM) grants currently support construction of safe rooms in tornado hazard areas and construction of earthen mounds in floodplains to permit livestock refuge from floodwaters. However, FEMA has not had the opportunity to fully investigate the feasibility of a tsunami mitigation project that provides similar benefits through the PDM program. However, new research indicates that many tsunami mitigation projects are, in fact, more cost-effective with higher benefit-cost ratios than most tornado or earthquake mitigation projects currently authorized by FEMA.[256]

This new line of research clearly indicates that using FEMA's value of life, discount rate, and project useful life, provides ample economic justification for tsunami mitigation projects in high risk locations. Perhaps more importantly, these results also identify that national and local priorities for natural hazard mitigation should be reconsidered, with tsunami mitigation given a very high priority for coastal communities.

To reduce the potential life safety impacts from a Cascadia tsunami, WA EMD initiated Project Safe Haven in order to identify vertical evacuation options for outer coastal and tribal communities. Project Safe Haven is a grassroots, public planning process which empowers coastal residents to develop community-based plans that integrate multi-purpose vertical evacuation refuges into the existing natural and built environments. Subject matter experts facilitate the planning process and final plans have been completed for every tsunami threatened outer coastal and tribal community in Washington State. The final community-developed reports are available at: www.facebook.com/projectsafehaven.

Table 77 – Summary of Proposed Community Strategies and Projected Costs

County	Community Strategy	Population Served	Est. Projected Cost (in millions)
Clallam	2 towers, improving access to some existing high ground	1,755	$1.48
Grays Harbor	3 berms, 18 towers, 8 tower/berm hybrid facilities, 3 buildings	18,450	$40.00
Pacific	13 berms, 5 towers, 2 buildings	6,300	$11.00
TOTAL		26,505	$52.48

While no amount of planning, education and preparedness can make a community tsunami proof, personal and community preparedness can greatly reduce the amount of lives lost and property destroyed in the event that a tsunami strikes Washington's coast.

Previous Occurrences

Tsunamis on Washington's Pacific Coast [257, 258, 259, 260]

While tsunamis have caused significant damage, deaths, and injuries elsewhere in the world, only one significant tsunami struck Washington's Pacific coast in recent history. The 1964 Alaska earthquake generated a tsunami that resulted in more than $640,000 (in 2004 dollars) in damage. However, geologic investigations indicate that tsunamis have struck the coast a number of times in the last few hundred years.

1700 Cascadia Tsunami

The most recent Cascadia Subduction Zone earthquake, estimated at magnitude 9, produced a tsunami on Washington's coast in 1700. The tsunami overran Native American fishing camps and left behind telltale sheets of sand on marshes and in lakes along the southern part of the coast. A sand sheet at Discovery Bay in the eastern Strait of Juan de Fuca also probably resulted from the 1700 tsunami.

Japanese written history pinpoints this event to the evening of January 26, 1700. There, the tsunami began in the middle of the night of January 27-28 Japan time and continued until the following afternoon or evening. Its waves drove villagers to high ground, drowned their paddies and crops, damaged their salt kilns and fishing shacks, entered a government storehouse, and ascended a castle moat. It destroyed dozens of buildings, including 20 houses consumed by a fire that the flooding started or spread. It set in motion a nautical accident that sank tons of rice and killed two sailors. It led samurai to give rice to villagers left hungry and to request lumber for those left homeless. The tsunami left a village headman wondering why no earthquake had warned of its coming.

1960 Chilean Tsunami

A magnitude 9.5 earthquake along the coast of Chile generated a tsunami that struck the Washington coast at Grays Harbor (small waves), Tokeland (two feet), Ilwaco (two feet), Neah Bay (1.2 feet), and Friday Harbor (0.3 feet). No damage occurred.

1964 Alaskan Tsunami

The tsunami generated by the March 27, 1964 Alaska earthquake was the largest and best-recorded historical tsunami on the Washington coast. Tsunami wave heights generally were greatest on the south coast and smaller on the north coast. Additionally, the tsunami was recorded inland in the Strait of Juan de Fuca (Friday Harbor), Puget Sound (Seattle), and the Columbia River (Vancouver).

Observations were made of the tsunami in Grays Harbor County at Westport, Joe Creek, Pacific Beach, Copalis, Grays Harbor City, and Boone Creek.

Damages included debris deposits throughout the region, minor damage in Ilwaco, damage to two bridges on State Highway 109, a house and smaller buildings being lifted off foundations in Pacific Beach (the house was a total loss), and damage to the Highway 101 bridge over the Bone River near Bay Center when the Moore cannery building washed against its pilings.

Table 78 Recorded Height of Tsunami Waves from 1964 Alaska Earthquake

Wreck Creek	**4.5 feet**	**Neah Bay**	**0.7 feet**
Seaview	**3.8 feet**	**Taholah**	**0.7 feet**
Moclips	**3.4 feet**	**Hoh River Mouth**	**0.5 feet**
Ocean Shores	**2.9 feet**	**Friday Harbor**	**0.4 feet**
La Push	**1.6 feet**	**Vancouver**	**0.1 feet**
Ilwaco	**1.4 feet**	**Seattle**	**0.1 feet**

Additional information concerning observations from the 1964 tsunami on the Washington coast are highlighted below in an excerpt from the Tsunami Hazard Map of the Southern Washington Coast by Timothy Walsh, et al (2000). [261]

Table 1. Observations of the 1964 tsunami on the Washington coast. Height is height of highest wave; MLW, mean low water; MSL, mean sea level. Estimated damage is in 1964 dollars (from Hogan and others, 1964; Wilson and Torum, 1972; and newspaper accounts)

Location	Map no.	Height (ft) above tide	Height (ft) above MLW	Height (ft) above MSL	Estimated damage	Type of damage	Photo
Coast Guard Station, Cape Disappointment	1	5.7	11.9	8.3		None	
Town of Ilwaco	2	4.5	10.7	7.1		Minor damage	
Town of Seaview	3	12.5	19.5	14.8		None	
Ocean Shores	4	9.7	18.1	13.3		Deposition of debris on streets near Central Motel Office. Debris on streets and yards in vicinity of break in sand dune dike about ¾ mile south of motel	
State Highway 109, Copalis River Bridge	5					Loss of one four-pile timber bent and two timber spans near the bridge center and one piling in a four-pile timber bent.	9-1-A; Fig.3
Town of Copalis, Copalis River	6				$5,000	Damage to buildings	
State Hwy 109 at Boone Creek	7				$5,000	Erosion of 80 ft (24 m) of shoulder and deposition of debris on highway.	8-4-A
Iron Springs Resort	7				$500	Foundation and water damage to one house and deposition of debris in yard.	
State Highway 109, Joe Creek Bridge	8				$75,000	Loss of five-pile bent, damage to two pile bents (loss of three pilings), and loss of two 20-ft (6.1-m) reinforced concrete spans.	8-3-A; Fig. 4
Town of Pacific Beach	9	12–14 (est.)			$12,000	Medium-sized house lifted off the foundation and partly torn apart; total loss. Several sheds moved off foundations. A second building partly damaged. Yards eroded and covered with debris.	8-2-A; Fig. 5
Town of Moclips	10	11.1	19.7	14.9	$6,000	Damage to ocean side of buildings by floating logs; one building moved off foundation. Timber pile bulkheads and fills extensively damaged. Water over some floors from 6 in. to several feet. Heavy debris scattered over yards.	8-1-A, B,C; Figs. 6,7,8
State Highway 109, Wreck Creek Bridge	11	14.9	23.5	18.83	$500	Erosion of fill at bridge approach: debris on bridge deck and nearby highway.	7-1-A
Taholah	12	2.4	11.0	6.3	$1,000	Loss of several skiffs and fish nets in inlet at mouth of Quinault River.	
Mouth of Hoh River		1.7	10.1	5.6		None	
La Push		5.3	13.7	9.3		Several boats and a floating dock broke loose from moorings.	
U.S. Highway 101, Bone River Bridge	13					Pilings damaged when the Moore cannery building was lifted off its foundation and washed against the south approach of the Highway 101 bridge over the Bone River	
Raymond docks		3.5–4 (est.)				None	

November 2006 Tsunami

On Nov 15, 2006, a magnitude 8.3 earthquake occurred near the Kuril Islands northeast of Japan. Washington was put into a Tsunami Advisory. A 5 cm tsunami was recorded on the Neah Bay tide gage. However, after the cancellation of the Tsunami Advisory, a train of tsunami waves hit Crescent City, California six hours after the earthquake and destroyed docks, tore about a dozen boats lose from moorings, and sank at least one boat.

Table 79. Recorded Height of Tsunami Waves from 2006 Kuril Island Earthquake	
Location	**Wave height**
La Push	**.52 feet**
Neah Bay	**.01 feet**
Port Angeles	**.39 feet**
Westport	**.16 feet**

Puget Sound Tsunamis [262, 263, 264, 265, 266]

A.D. 900-930 Tsunami

An earthquake between the years 900 and 930 raised shores of central Puget Sound by 20 feet between the Duwamish River and Bremerton. The uplift, by also including the floor of Puget Sound, created a tsunami. In Seattle, the tsunami washed across West Point, where it deposited a sheet of sand. Farther north, it deposited a sand sheet at Cultus Bay on southern Whidbey Island and along tributaries of the Snohomish River between Everett and Marysville. Computer simulations of the tsunami show it reaching heights of 20 feet or more at the Seattle waterfront.

Early 1800s Camano Head Tsunami

Historical accounts among the Snohomish Indian people describe a landslide at Camano Head that sent a large wave south toward Hat Island. Camano Head is at the south end of Camano Island in Puget Sound. According to tribal accounts, the landslide sounded like thunder, buried a small village, and created a large volume of dust. The tsunami washed over the barrier beach at Hat Island, destroying homes or encampments and drowning many people. The accounts make no mention of ground shaking, suggesting that the slide was not associated with a large earthquake.

1891 Puget Sound Tsunami

Water in Lake Washington and Puget Sound surged onto beaches two feet above the high water mark, rocking vessels that had just pulled away from wharves, and causing an elevator in one building to bump against the side of the shaft. The likely cause of this November 29 event was two earthquake shocks and submarine landslides.

1894 Commencement Bay Tsunami

A submarine landslide in the delta of the Puyallup River in Commencement Bay, Tacoma, caused a tsunami. These events carried away a railroad track and roadway, resulting in two deaths.

1949 Puget Sound Tsunami

A small landslide-generated tsunami struck the Point Defiance shoreline in the Tacoma Narrows on April 16, three days after a magnitude 7.1 earthquake weakened the hillside. According to local newspaper reports, an 11 million cubic yard landslide occurred when a 400-foot high cliff gave way and slid into Puget Sound. Water receded 20-25 feet from the normal tide line, and an eight-foot wave rushed back against the beach, smashing boats, docks, a wooden boardwalk, and other waterfront installations in the Salmon Beach area. The slide narrowly missed a row of waterfront homes struck by the tsunami.

Inland Tsunamis[267]

Lake Roosevelt Tsunamis

Landslides into Lake Roosevelt in eastern Washington generated numerous tsunamis from 1944 to 1953 after Grand Coulee Dam created the lake on the Columbia River. Most tsunamis generated large waves (30 to 60 feet in height) that struck the opposite shore of the lake, with some waves observed miles from the source. Two tsunamis caused damage:

February 23, 1951 – A 100,000 to 200,000 cubic yard landslide just north of Kettle Falls created a wave that picked up logs at the Harter Lumber Company Mill and flung them through the mill 10 feet above lake level.

October 13, 1952 – A landslide 98 miles upstream of Grand Coulee Dam created a wave that broke tugboats and barges loose from their moorings at the Lafferty Transportation Company six miles away. It also swept logs and other debris over a large area above lake level.

January 16, 2009—Another landslide –induced tsunami reached a height of about 30 feet and damaged docks at Breezy Bay, Moccasin Bay, Sunset Point, and Arrowhead Point.

1965 Puget Island Tsunami

This tsunami occurred in 1965. A landslide-triggered tsunami overran Puget Island in the Columbia River near Cathlamet. The landslide originated from Bradwood Point on the Oregon side of the River. The wave killed one person.

1980 Spirit Lake Tsunami

The May 18, 1980 eruption of Mount St. Helens caused a massive tsunami in Spirit Lake. The sliding north face of the volcano slammed into the west arm of the lake, raising its surface an estimated 207 feet and sending a tsunami surging around the lake basin as high as 820 feet above the previous lake level. Displaced water rinsed the valley sides clean of timber and sediment, jamming logs and boulders against the landslide debris. In the east arm of Spirit Lake, the tsunami wave reached nearly 740 feet above the old level of the lake, also washing trees off the sides of the valley and into the lake.

Seiche [268, 269, 270]

Seiches are water waves generated in enclosed or partly enclosed bodies of water such as reservoirs, lakes, bays and rivers by the passage of seismic waves (ground shaking) caused by earthquakes. Sedimentary basins beneath the body of water can amplify a seiche. Seismic waves also can amplify water waves by exciting the natural sloshing action in a body of water or focusing water waves onto a section of shoreline.

In a 2003 paper, researchers at the University of Washington and the National Oceanic and Atmospheric Administration indicate that the geology of the sedimentary basin beneath Seattle amplifies seismic waves from large and distant earthquakes, contributing to the damaging effects of water waves in local enclosed bodies of water.

The November 2002 magnitude 7.9 Denali earthquake in Alaska produced water waves damaging about 20 houseboats in Seattle's Lake Union, buckling moorings, and breaking sewer and water lines. Sloshing action was reported in swimming pools, ponds, and lakes around Seattle. Newspaper reports indicate water waves from the 1964 magnitude 9.2 Alaska earthquake caused similar damage on the lake as well as overtopping the Fairview Hill reservoir and washing gravel into an Aberdeen neighborhood. Sloshing wave action also was reported following the 1949 magnitude 7.1 Olympia earthquake and the 1965 magnitude 6.5 Seattle earthquake.

Researchers believe local amplification of seismic waves could make other urban areas above sedimentary basins in the region particularly vulnerable to seiches or water waves during large earthquakes on the Seattle Fault or the Cascadia Subduction Zone.

Probability of Future Events[271]

Great earthquakes in the Pacific Ocean generate tsunamis that sweep through the entire Pacific basin at a rate of about six every 100 years. In the Cascadia Subduction Zone, scientists currently estimate there is a 10 to 14 percent chance a magnitude 9.0 earthquake and associated tsunami will occur in the next 50 years.

A specific rate of occurrence has not been calculated for local earthquakes and landslides that generate tsunamis.

Jurisdictions Most Threatened and Vulnerable to Tsunami [272, 273, 274]

Areas vulnerable to tsunamis in Washington State include ocean beaches, bay entrances, tidal flats, the banks of tidal rivers, and some inland waters.

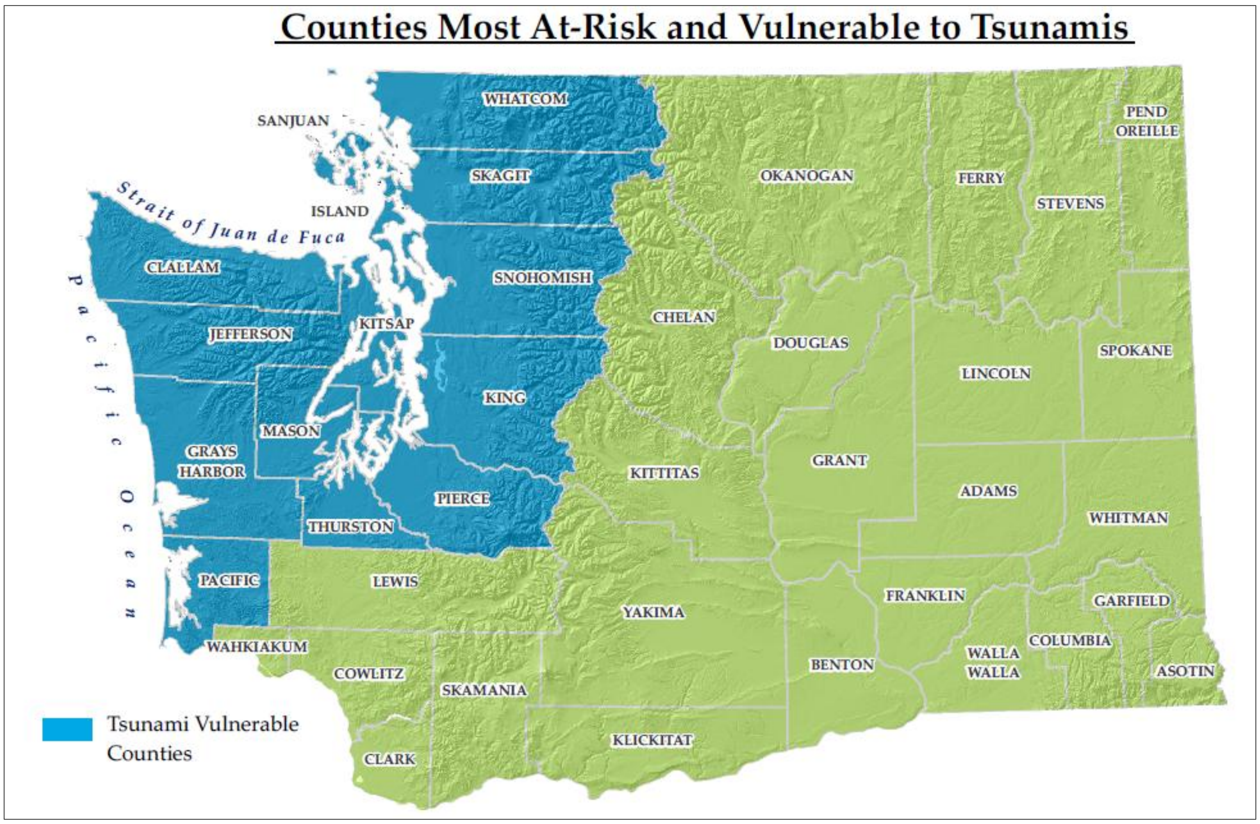
Washington began creating tsunami inundation models and maps for its Pacific Coast shoreline in the late 1990s using funds from the National Tsunami Hazard Mitigation Program. To date, tsunami inundation mapping for a Cascadia Subduction Zone earthquake is complete for most shorelines of the Pacific Coast and Strait of Juan de Fuca. Modeling and mapping is complete for an earthquake on the Seattle Fault for Seattle and Tacoma, and on the Tacoma Fault for Tacoma. Modeling for tsunamis caused by surface faults in the Everett area and in Lake Washington is underway or scheduled.

The Washington Department of Natural Resources Division of Geology and Earth Resources prepares tsunami inundation maps from the modeling. Local governments then use inundation maps to develop evacuation maps for their communities.

The state map below highlights the counties considered most at-risk and vulnerable to tsunamis; the latest inundation maps, population estimates, and communities considered most at risk are on the pages that follow. A study co-sponsored by the State Emergency Management Division and the U.S. Geological Survey completed in 2008 provides more detailed estimates on population, infrastructure and local economic assets in the Cascadia-related tsunami-hazard zones of Clallam, Jefferson, Grays Harbor and Pacific counties).

Estimates for state agency facilities located in the tsunami hazard zone were developed using the inundation maps on the following pages.

Figure 89 Counties Most at-Risk to Tsunamis



Pacific Coast, Strait of Juan de Fuca[275, 276, 277, 278]

The National Tsunami Hazard Mitigation Program's Center for Tsunami Inundation Mapping Efforts models uses a magnitude 9.1 earthquake on the Cascadia Subduction Zone off the Washington coast as the generator of the tsunami.

The estimated at-risk population in the four counties bordering the outer Pacific Coast is 42,972 residents (based on the 2000 U.S. Census), representing 24% of the total people in these counties (Wood and Soulard, 2008). It does not include at-risk communities on the east end of the Strait of Juan de Fuca such as Bellingham, Anacortes and Mount Vernon, and Island and San Juan counties; their at-risk populations have not been calculated.

Within the four counties bordering the Pacific Ocean, the City of Aberdeen has the highest number of residents (11,781) in the tsunami-inundation zone. Approximately 13,096 residents in tsunami-prone areas are outside of the 13 incorporated cities and 7 Indian reservations and are primarily in the unincorporated portions of Pacific County (6,823) and Grays Harbor County (3,957). Many communities have low numbers but high percentages of residents in the tsunami-inundation zone, including the Makah Indian Reservation (802 residents, representing 59 percent of the community), the Hoh Indian Reservation (62 residents, 61 percent), South Bend (900 residents, 50 percent), and Long Beach (1,281 residents, 100 percent).

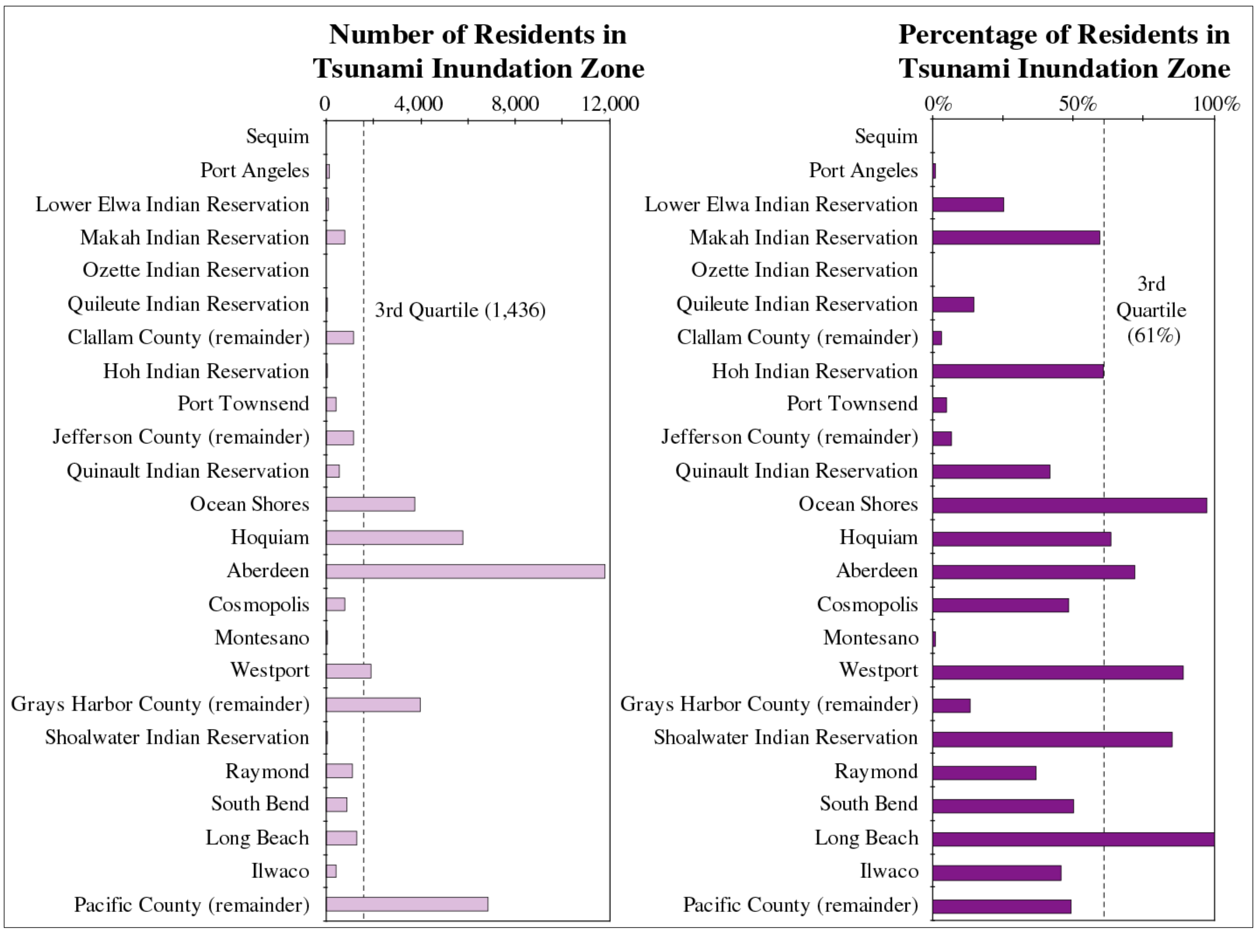
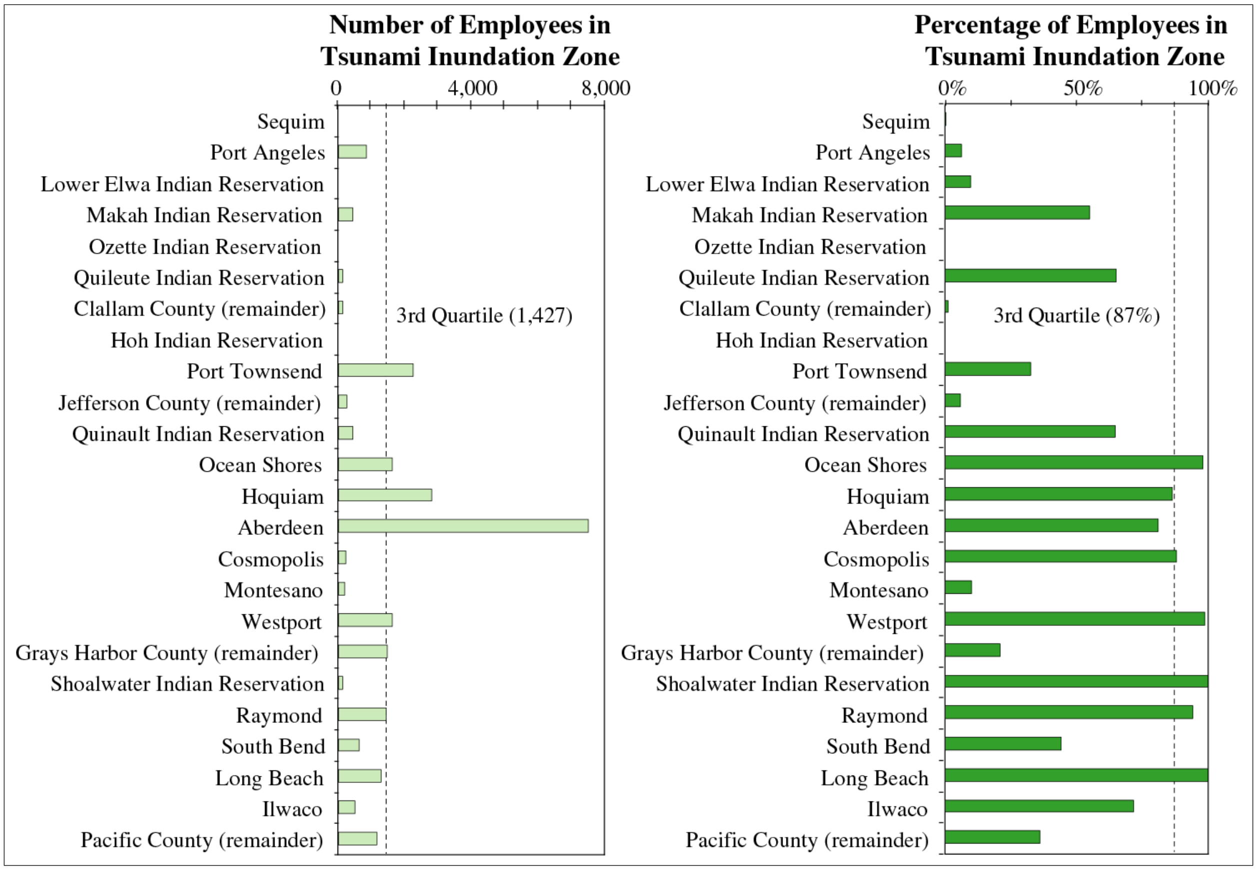


Figure 90 Residents in Tsunami Inundation Zones

The tsunami-inundation zone contains 24,934 employees (based on 2007 economic data), representing 33 percent of the employees in the four coastal counties (Wood and Soulard, 2008). Certain communities such as Hoquiam and Aberdeen have high numbers of employees in the tsunami-inundation zone (2,792 and 7,488, respectively) that represents high percentages of their community workforce (86 percent and 81 percent, respectively). Other communities have much lower numbers of employees in the tsunami-inundation zone, including Shoalwater Indian Reservation (138), but these employees represent the entire community workforce.

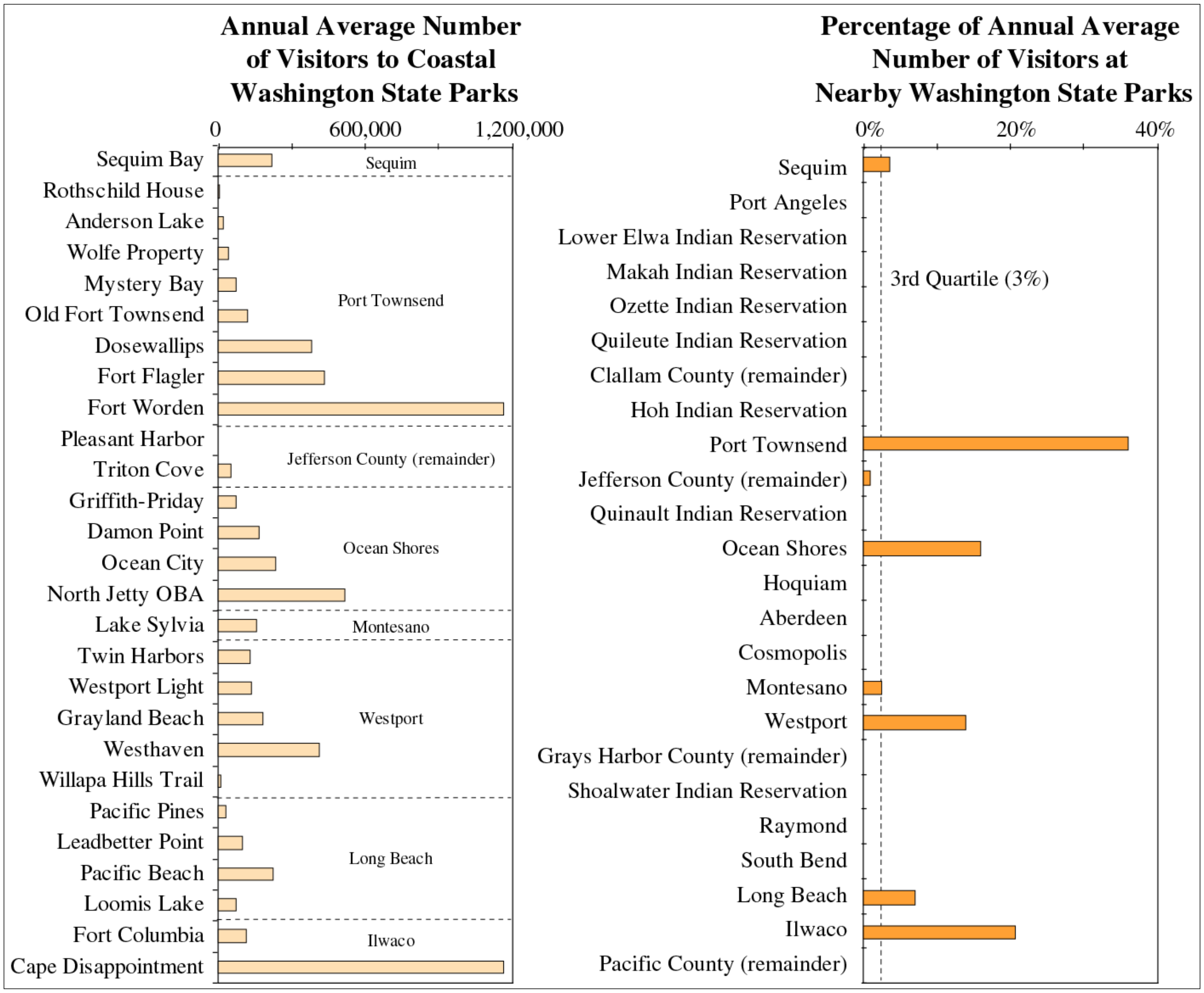
Figure 91 Employees in Tsunami Inundation Zones



These at-risk population estimates exclude the thousands of tourists that populate at-risk beach areas at various times of the year. Analysis of visitor data from Washington State Parks in Wood and Soulard (2008) suggests that 27 parks in the tsunami-inundation zone of the study area receive a significant amount of day tourists. The highest annual average of day-use visitors for the 27 parks are for Fort Worden (1,164,125 visitors near Port Townsend) and Cape Disappointment (1,162,447 visitors near Ilwaco). The sum of annual average visitors to the 27 coastal parks of the Washington State parks selected in Wood and Soulard (2008) is 6,215,569 people (2007 estimates).

Assuming an equal distribution of visitors on every day of the year, this equates to 17,029 day-use visitors to these coastal State parks on average every day. In reality, this number is low because attendance is not equally distributed throughout the year; there will be seasonal peaks in park attendance (for example, summer months and holidays). Clustering the number of visitors of coastal parks to nearby towns, it is clear that the majority of visitors are going to parks near Port Townsend (36 percent) on the Strait of Juan de Fuca and Hood Canal coasts, followed by parks near Ilwaco (21 percent), Ocean Shores (16 percent), and Westport (14 percent). Therefore, in addition to dealing with residents and employees within the tsunami-inundation zones of their communities, cities like Port Townsend may have significant numbers of tourists that are visiting nearby State Parks when a tsunami occurs.

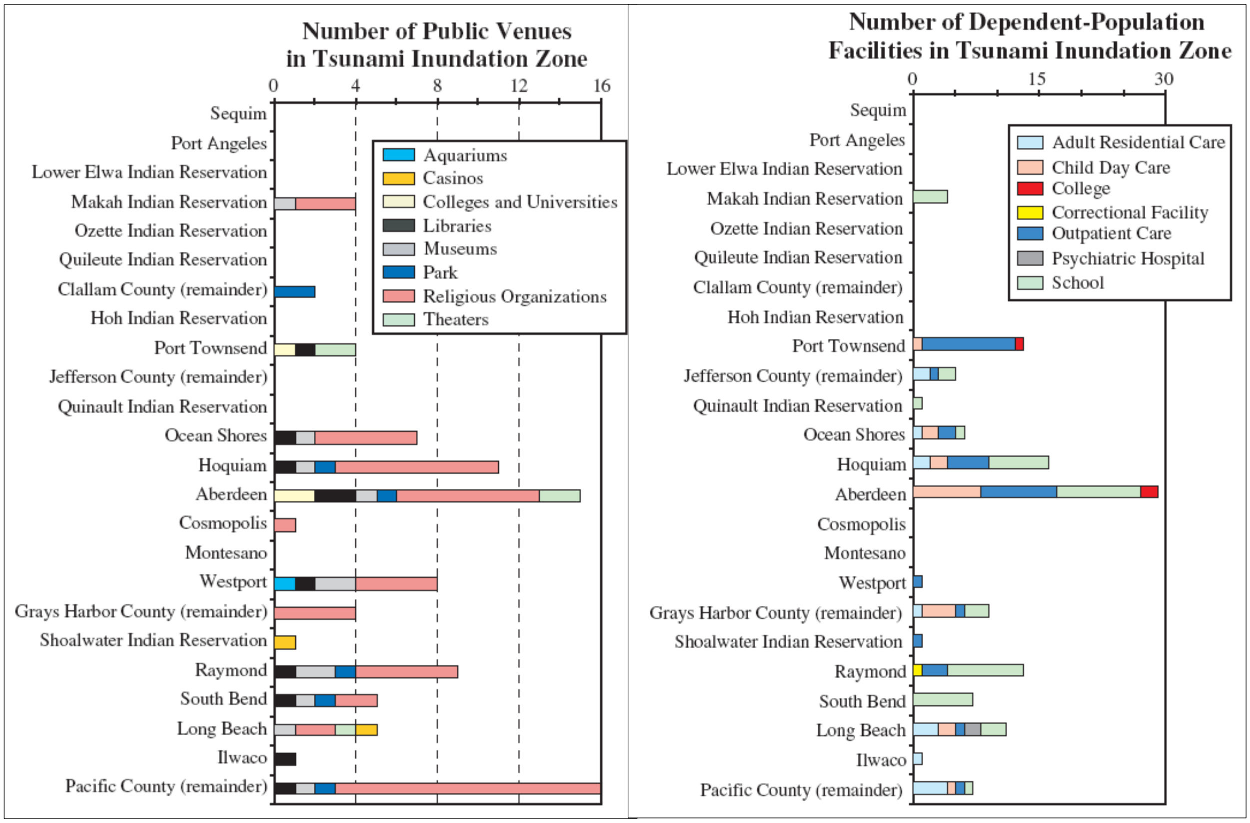
Figure 92 Visitors in Tsunami Inundation Zones



The tsunami-hazard zone of the four counties bordering the Pacific Ocean also contains several public venues that likely attract high numbers of local populations (Wood and Soulard, 2008). The highest number of public venues in the tsunami-inundation zone are in the unincorporated areas of Pacific County (16 facilities) and the majority of them are religious facilities (for example, churches). The next highest numbers of public venues in the tsunami-inundation zone are in the coastal communities of Grays Harbor County (for example, Aberdeen, Ocean Shores, Hoquiam, and Westport).

This tsunami-hazard zone also contains several dependent-population facilities that house individuals that would require evacuation assistance in the event of a tsunami warning (Wood and Soulard, 2008). Many of these facilities are in central-coast communities, specifically the cities of Aberdeen and Hoquiam

Figure 93 Facilities in Tsunami Inundation Zones



The tsunami-inundation zone of the four counties bordering the Pacific Ocean contains parcel values assessed at approximately $4.5 billion (2007 U.S. dollars), representing 25 percent of the total parcel values in the four coastal counties (Wood and Soulard, 2008). The highest total exposed tax parcel values for the 20 communities are in Aberdeen ($887 million) and Ocean Shores ($759 million), representing 71 percent and 99 percent, respectively, of the total tax base in the communities. The third highest total parcel values is in the unincorporated portion of Pacific County, primarily reflecting the unincorporated town of Ocean Park. Although many communities have relatively low amounts of total parcel value in the tsunami-inundation zones, the exposed parcels represent a high percentage of a community's total assets. Building damages due to CSZ-related tsunamis, as well as from the preceding earthquake, could significantly lower the content value of individual properties, thereby lowering the tax base of a community after a tsunami disaster, and reducing the funds available for long-term recovery.

Figure 94 Parcel Values in Tsunami Inundation Zones

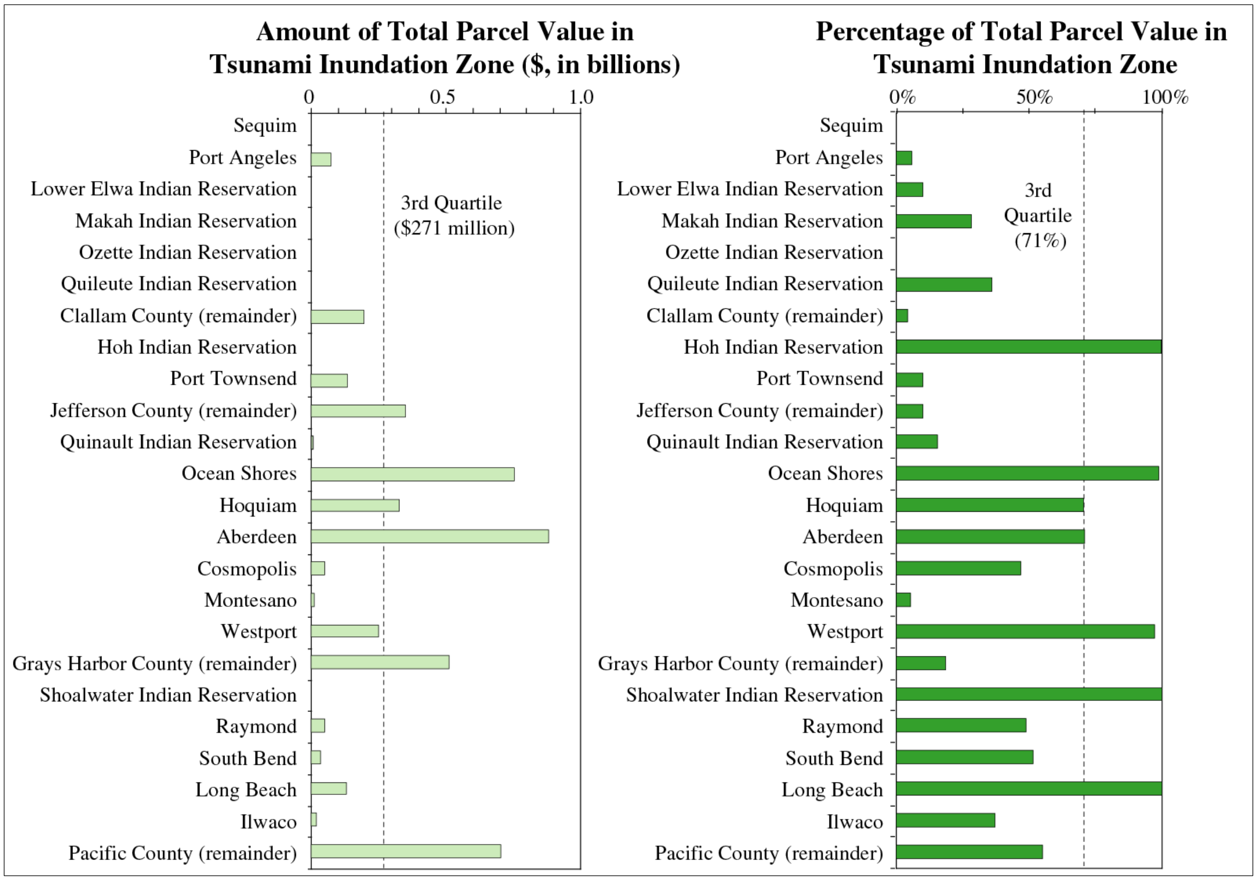

Amount of Total Parcel Value in Tsunami Inundation Zone ($, in billions)
0
0.5
1.0
3rd Quartile ($271 million)
Percentage of Total Parcel Value in Tsunami Inundation Zone
0%
50%
100%
3rd Quartile (71%)
Sequim
Port Angeles
Lower Elwa Indian Reservation
Makah Indian Reservation
Ozette Indian Reservation
Quileute Indian Reservation
Clallam County (remainder)
Hoh Indian Reservation
Port Townsend
Jefferson County (remainder)
Quinault Indian Reservation
Ocean Shores
Hoquiam
Aberdeen
Cosmopolis
Montesano
Westport
Grays Harbor County (remainder)
Shoalwater Indian Reservation
Raymond
South Bend
Long Beach
Ilwaco
Pacific County (remainder)

Table 80 Projected Cascadia Tsunami Wave Heights For At-Risk Coastal Communities	
Ocean Park	**29 Feet**
Sunset Beach	**20 Feet**
Grayland	**19 Feet**
Long Beach	**18 Feet**
Westport, Ocean Shores	**15 Feet**
Quileute	**13 Feet**
Port Angeles	**11 Feet**
Neah Bay	**10 Feet**
Port Townsend	**10 Feet**
Aberdeen, Hoquiam	**4 Feet**
Note: Tsunami wave height may be larger depending upon local tide conditions. [279, 280, 281, 282, 283, 284]	

A Cascadia tsunami would overtop several at-risk coastal communities including Bay Center, Long Beach, Ocean Park, Ocean Shores, Raymond, and Westport. Many of these communities are popular with tourists year-round.

At-risk tribal communities include the Makah, Hoh, Quinault, Shoalwater, Quileute, and Lower Elwha Indian nations, each with small reservations in low-lying coastal areas. Most coastal Tribes need assistance as they have little to no infrastructure to support emergency planning and response.

The first tsunami wave will arrive in at-risk communities on the outer coast 30 to 60 minutes after a great Cascadia earthquake, and about 90 minutes later in at-risk communities along the Strait of Juan de Fuca. Significant flooding is expected before the first wave because the earthquake will lower the elevation of the coast about five feet.[285] Maximum flood depth and extent of flooding will depend on tide height at the time of tsunami arrival.

Pacific County

– Estimated at-risk residential population: 10,595 (50% of total)
– Estimated at-risk employee population: 5,096 (57% of total)

Table 81 Pacific County				
Incorporated City or Tribal Community	**Number of Residents in Tsunami-Hazard Zone**	**Percentage of Community Residents**	**Number of Employees in Tsunami-Hazard Zone**	**Percentage of Community Employees**
Shoalwater Indian Reservation	**59**	**85%**	**138**	**100%**
Raymond	**1,098**	**37%**	**1,417**	**94%**
South Bend	**900**	**50%**	**630**	**44%**
Long Beach	**1,281**	**100%**	**1,259**	**100%**
Ilwaco	**433**	**46%**	**503**	**72%**
Pacific County (remainder)	**6,823**	**49%**	**1,149**	**36%**

Communities with population at risk: Bay Center, Ilwaco, Long Beach, Ocean Park, Raymond, South Bend, Tokeland.

Figure 95 Pacific County Tsunami Inundation Map

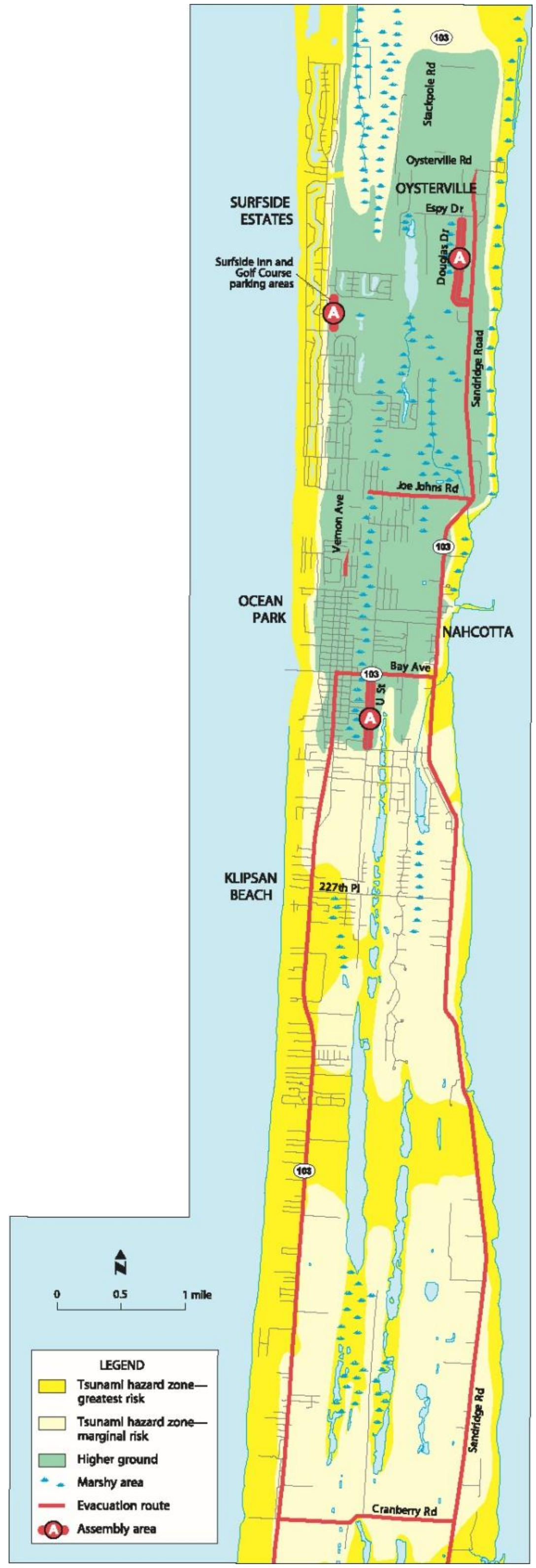
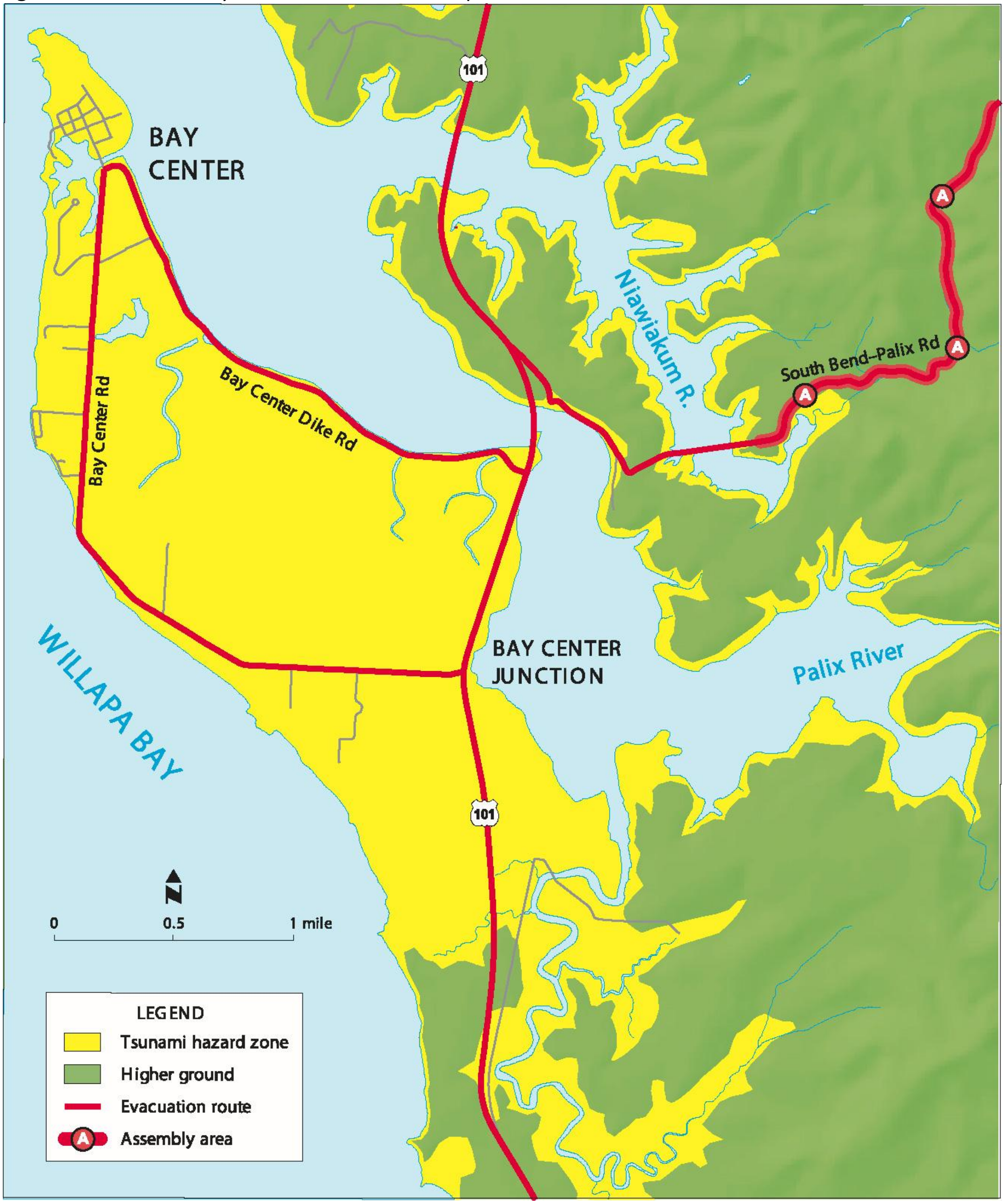


Figure 96 Pacific County Tsunami Inundation Map



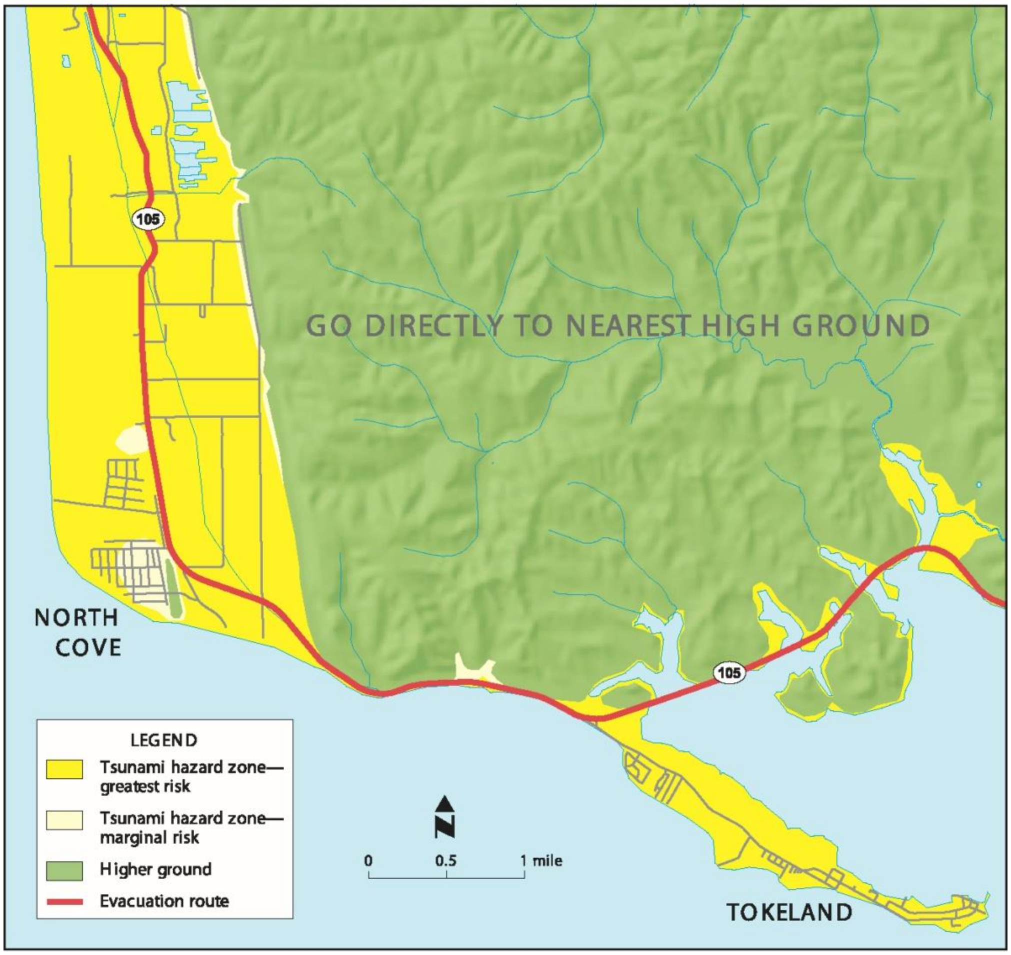
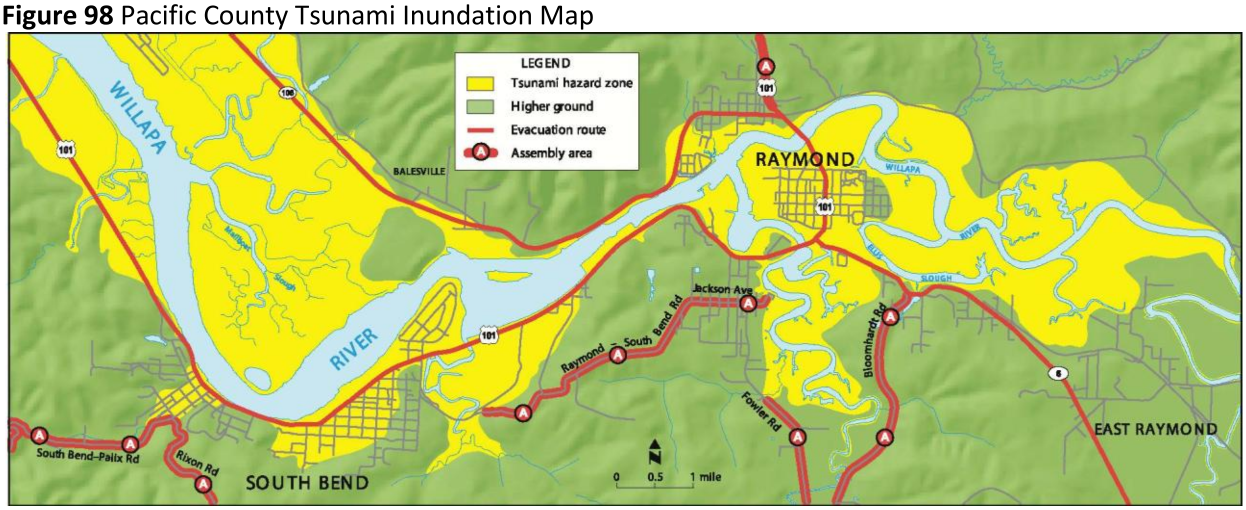


Figure 97 Pacific County Tsunami Inundation Map

Figure 98 Pacific County Tsunami Inundation Map



Grays Harbor County
– Estimated at-risk population: 28,447 (42% of total)
– Estimated at-risk employee population: 15,816 (62% of total)

Communities with population at risk: Aberdeen, Cohassett Beach, Copalis Beach, Grayland, Hoquiam, Markham, Moclips, Ocean City, Ocean Shores, Oyhut-Hogans Corner, Taholah, Westport.

Table 82 Grays Harbor County

Incorporated City or Tribal Community	Number of Residents in Tsunami-Hazard Zone	Percentage of Community Residents	Number of Employees in Tsunami-Hazard Zone	Percentage of Community Employees
Quinault Indian Reservation	572	42%	449	65%
Ocean Shores	3,733	97%	1,603	98%
Hoquiam	5,756	63%	2,792	86%
Aberdeen	11,781	72%	7,488	81%
Cosmopolis	768	48%	229	88%
Montesano	28	1%	178	10%
Westport	1,900	89%	1,619	99%
Grays Harbor County (remainder)	3,957	13%	1,458	21%

Figure 99 Grays Harbor County Tsunami Inundation Map

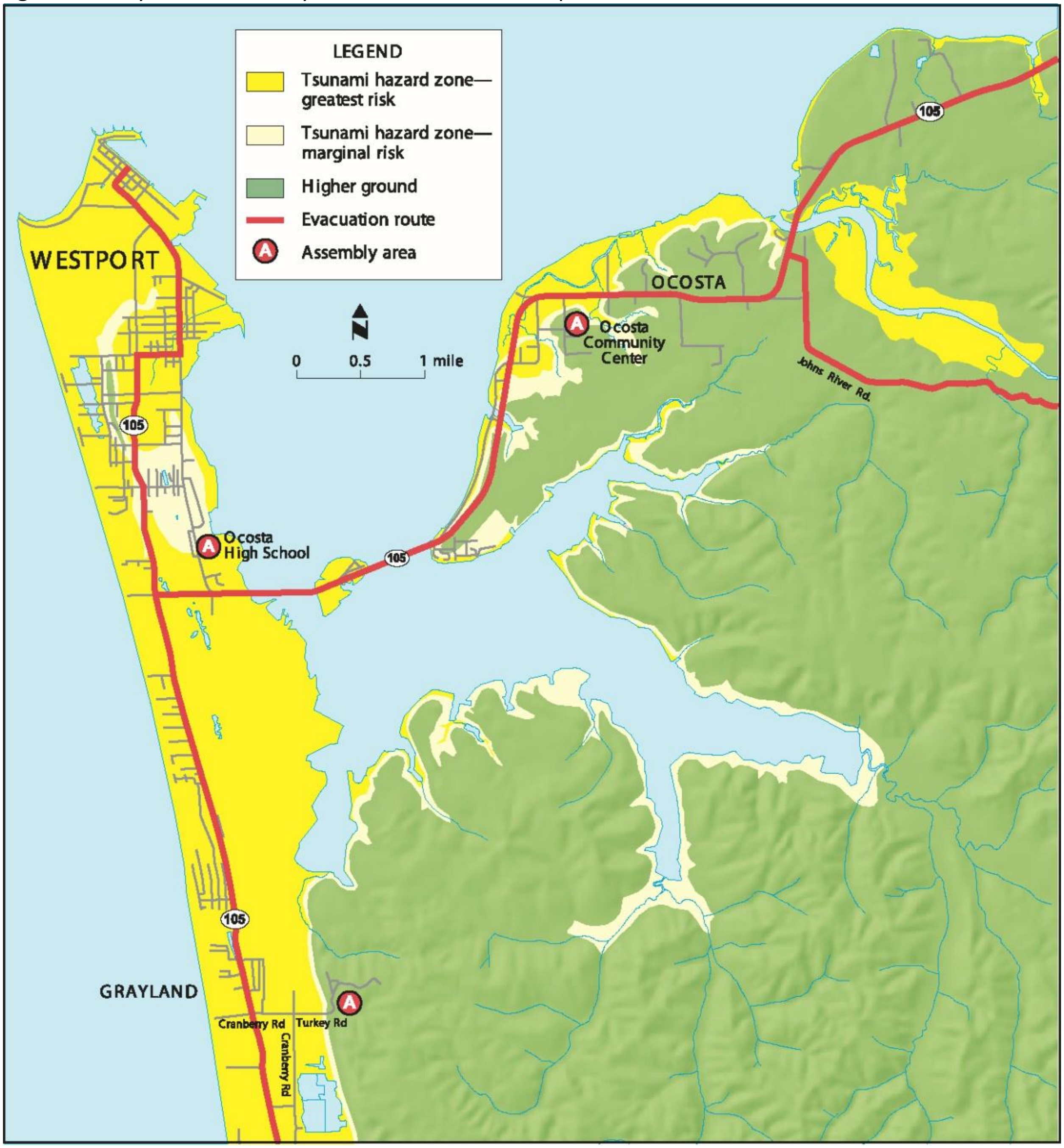


Figure 100 Grays Harbor County Tsunami Inundation Map

Figure 101 Grays Harbor County Tsunami Inundation Map

Figure 102 Grays Harbor County Tsunami Inundation Map

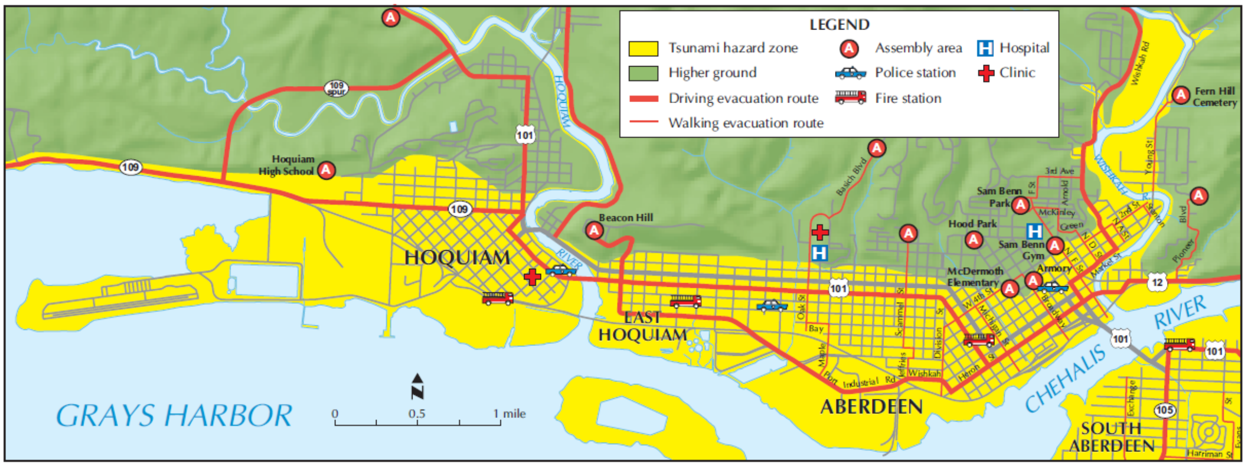
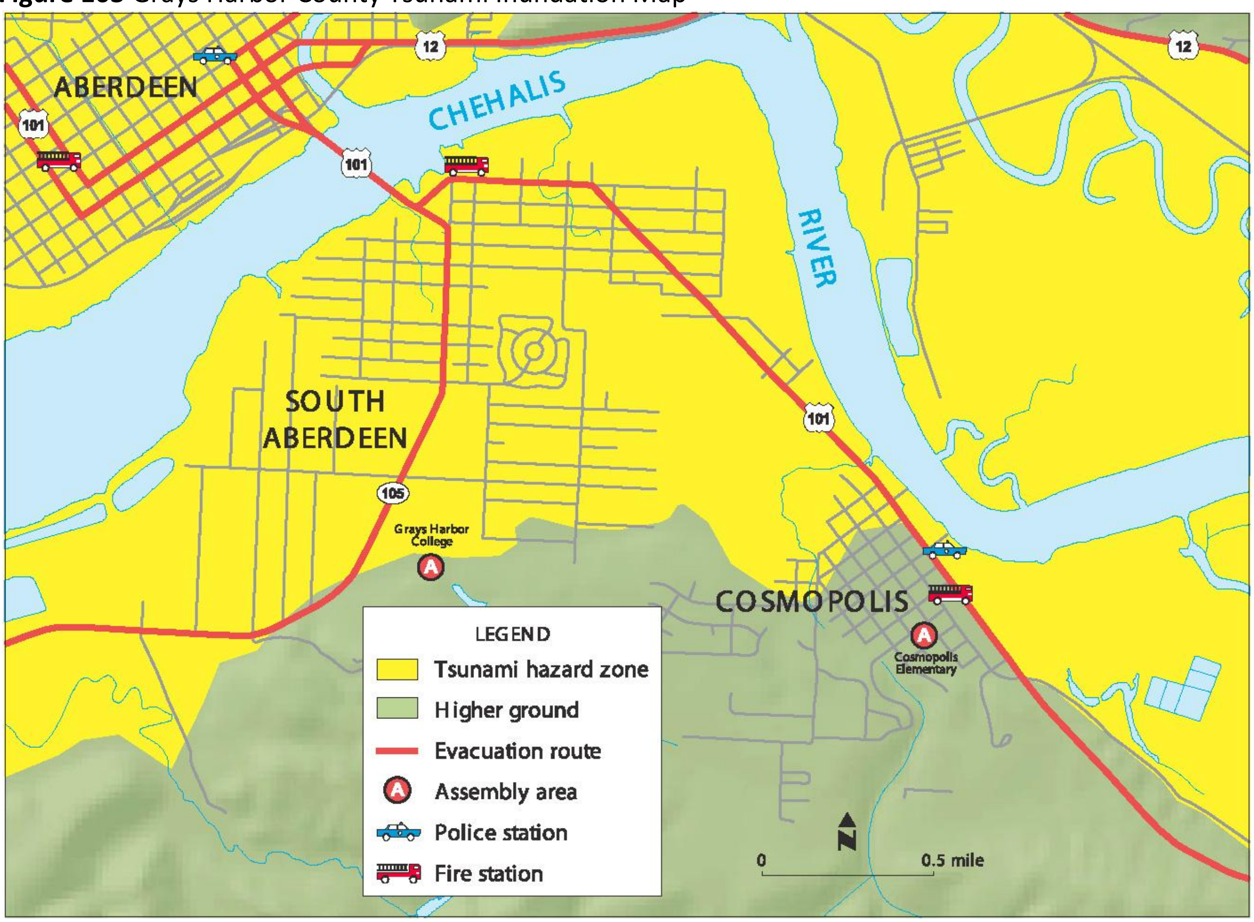


Figure 103 Grays Harbor County Tsunami Inundation Map



Clallam County

– Estimated at-risk residential population: 2,239 (3% of total)
– Estimated at-risk employee population: 1,550 (5% of total)

Communities with population at risk: Clallam Bay, La Push, Neah Bay, Port Angeles, Sequim

Table 83 Clallam County

Incorporated City or Tribal Community	Number of Residents in Tsunami-Hazard Zone	Percentage of Community Residents	Number of Employees in Tsunami-Hazard Zone	Percentage of Community Employees
Sequim	0	0%	15	0%
Port Angeles	143	1%	849	6%
Lower Elwa Indian Reservation	80	25%	4	10%
Makah Indian Reservation	802	59%	434	55%
Quileute Indian Reservation	54	15%	138	65%
Clallam County (remainder)	1,159	3%	110	1%

Figure 104 Clallam County Tsunami Inundation Map

Figure 105 Clallam County Tsunami Inundation Map

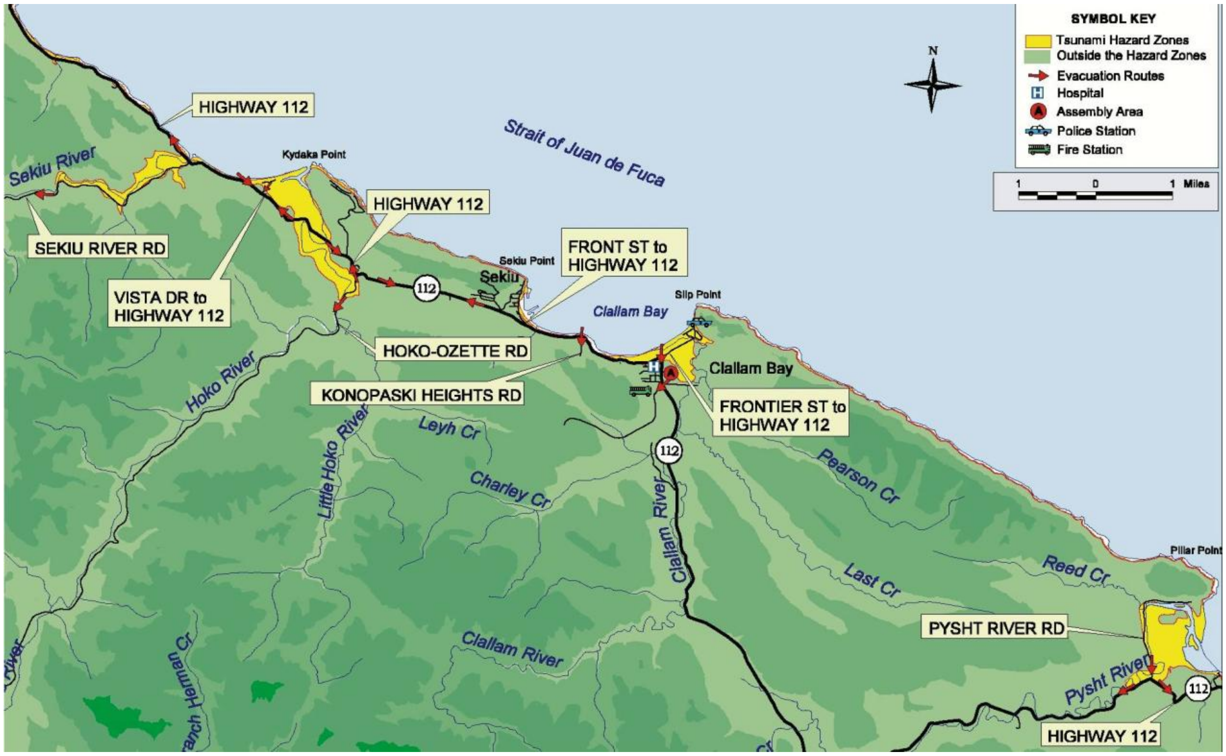


Figure 106 Clallam County Tsunami Inundation Map

Figure 107 Clallam County Tsunami Inundation Map

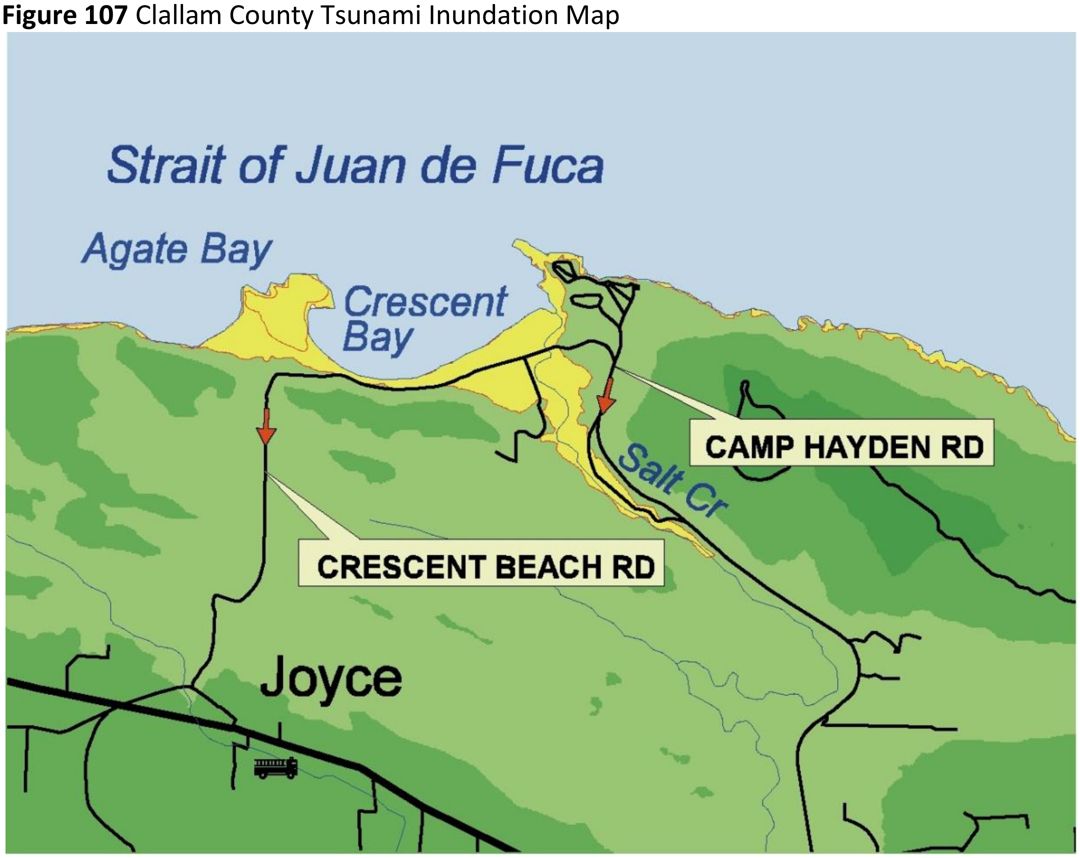


Figure 108 Clallam County Tsunami Inundation Map

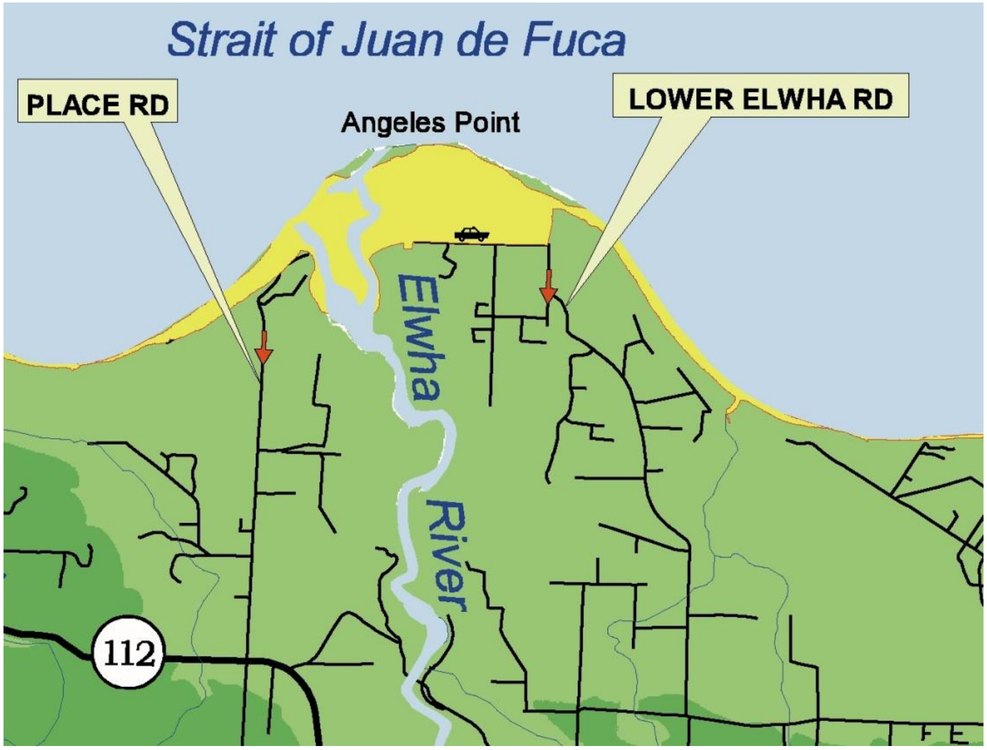
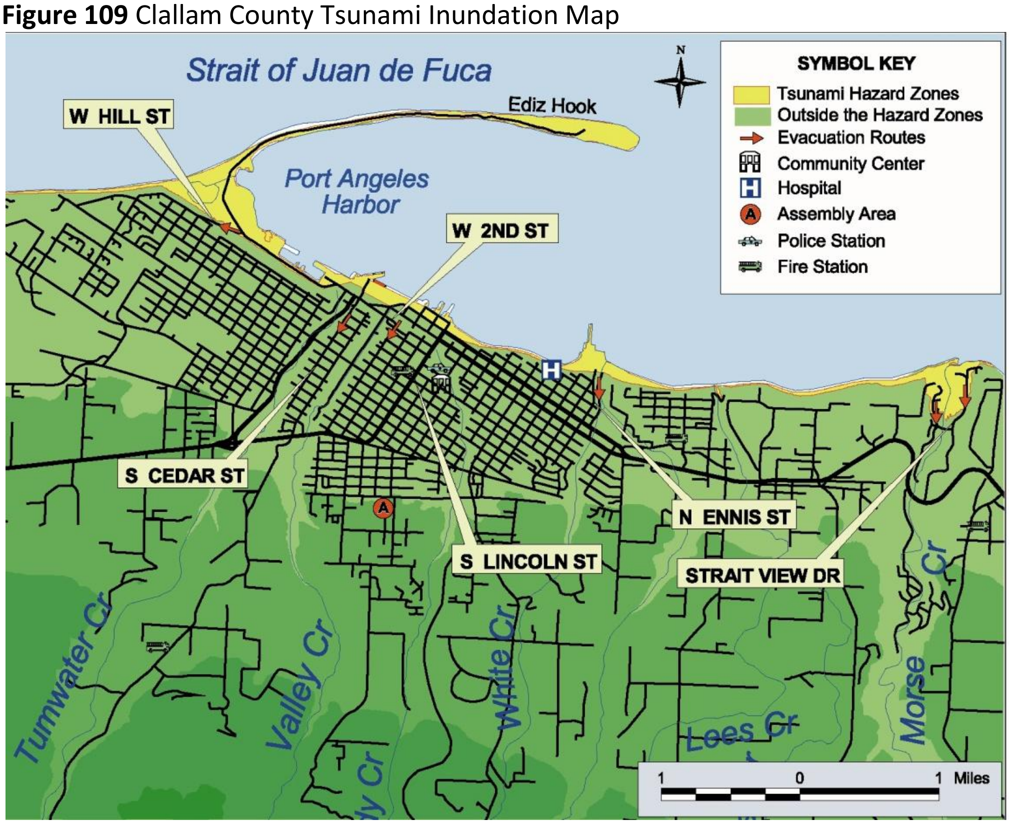


Figure 109 Clallam County Tsunami Inundation Map



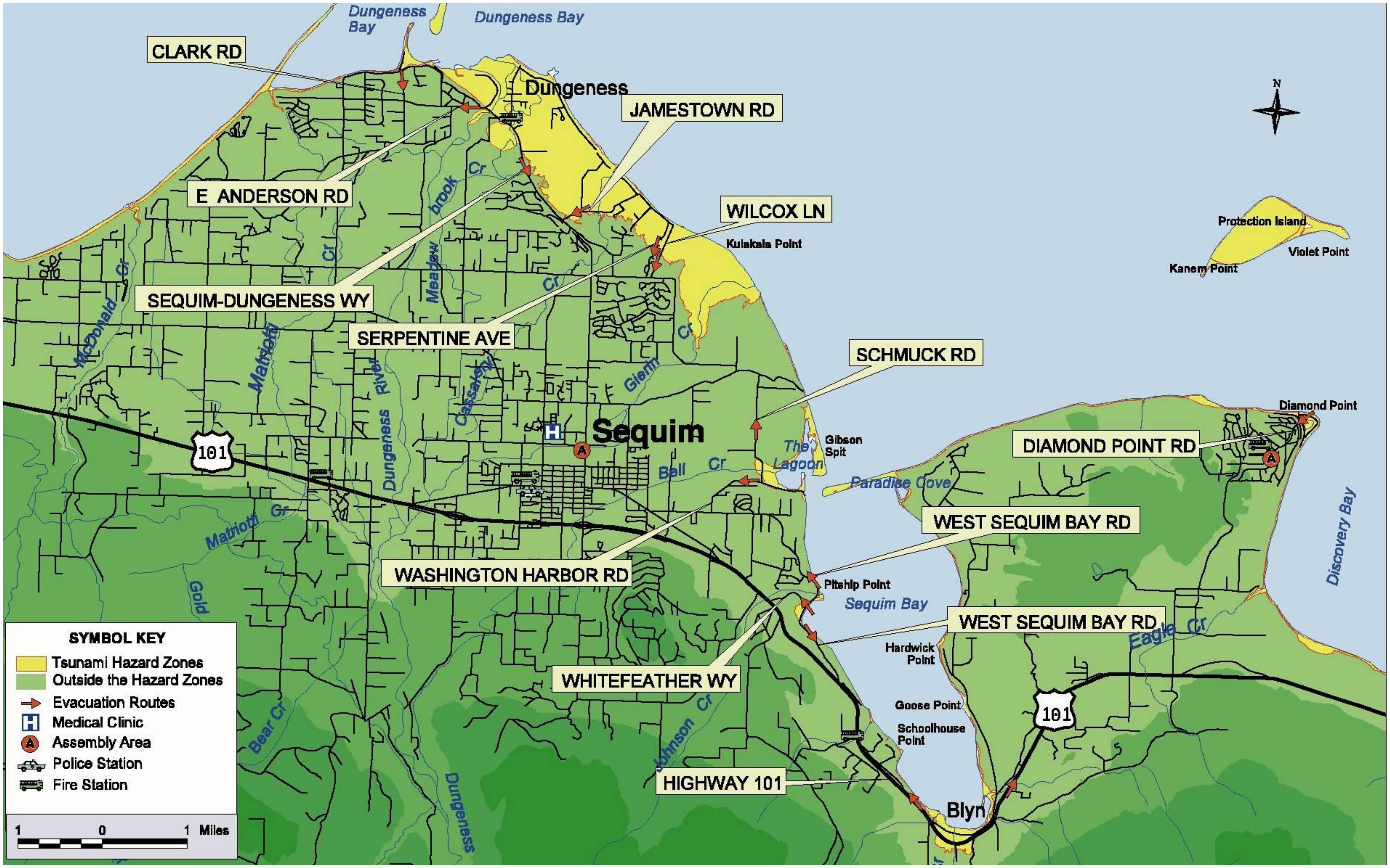


Figure 110 Clallam County Tsunami Inundation Map

Jefferson County

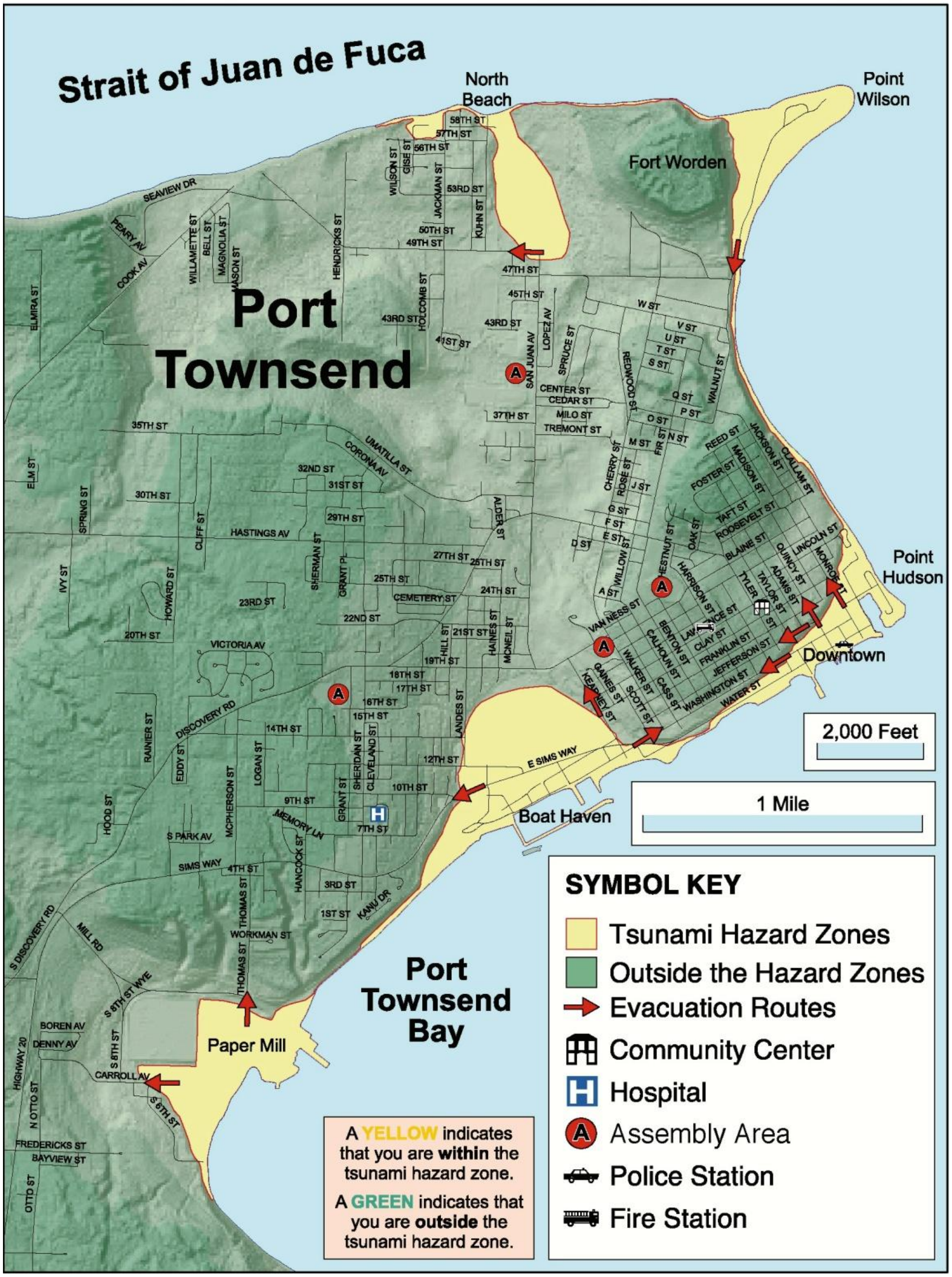
– Estimated at-risk residential population: 1,692 (7% of total)
– Estimated at-risk employee population: 2,472 (23% of total)

Communities with population at risk: Marrowstone Island, Port Hadlock-Irondale, Port Townsend.

Table 84 Jefferson County

Incorporated City or Tribal Community	Number of Residents in Tsunami-Hazard Zone	Percentage of Community Residents	Number of Employees in Tsunami-Hazard Zone	Percentage of Community Employees
Hoh Indian Reservation	62	61%	0	0%
Port Townsend	424	5%	2,228	33%
Jefferson County (remainder)	1,157	7%	244	6%

Figure 111 Jefferson County Tsunami Inundation Map

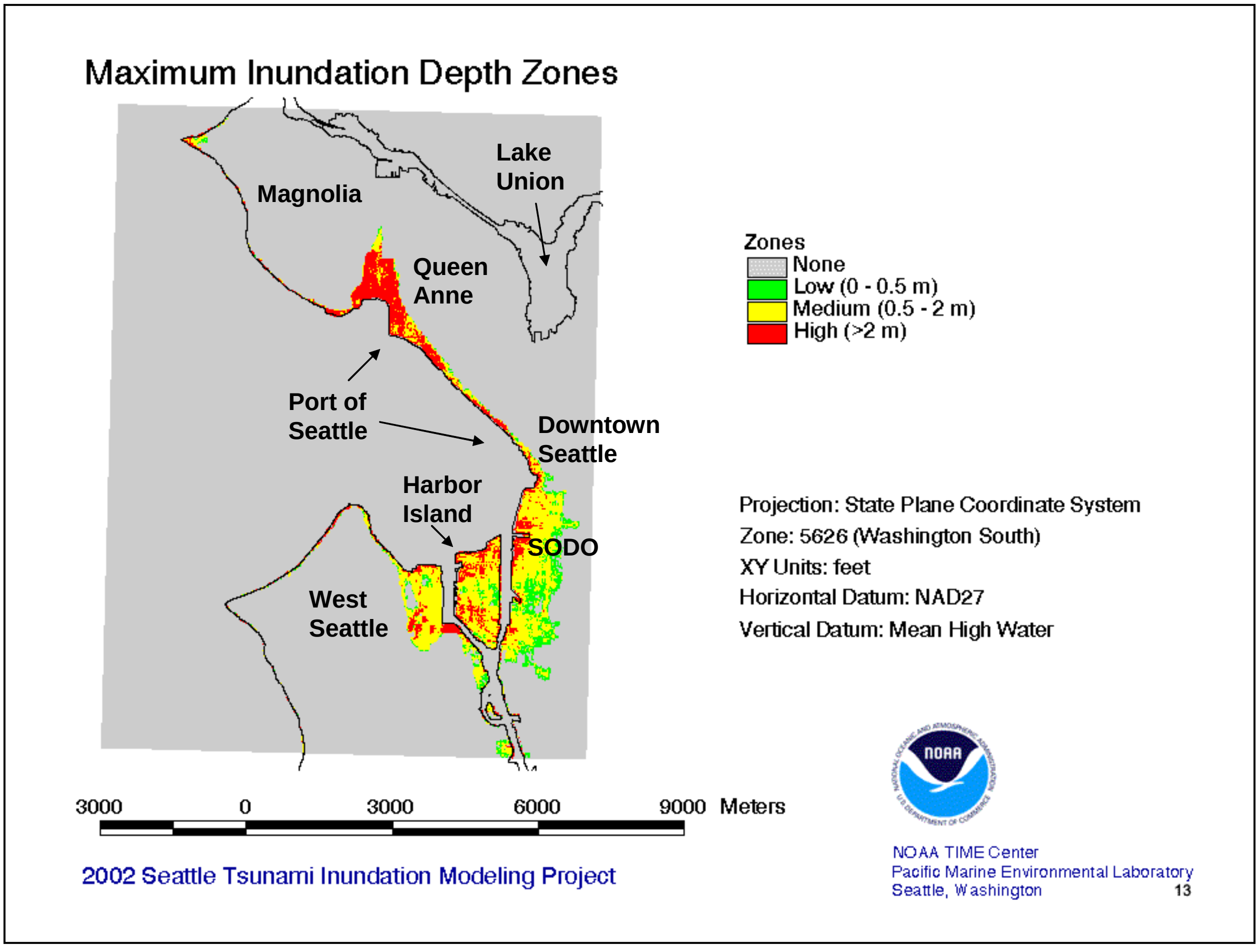


Seattle [286, 287]

The National Tsunami Hazard Mitigation Program's Center for Tsunami Inundation Mapping Efforts has developed a tsunami inundation model for Elliott Bay in Seattle using as an initiating event a magnitude 7.3 earthquake on the Seattle Fault, which roughly parallels Interstate 90 through Seattle. The area modeled includes the portions of Seattle highlighted on the map below. The projected at-risk population of this area is 42,466.

The tsunami is projected to hit the shoreline within two-and-a-half minutes of the earthquake and reach heights of up to 20 feet.

Figure 112 City of Seattle Tsunami Inundation Map



Eastern Strait of Juan de Fuca [288]

The National Tsunami Hazard Mitigation Program's Center for Tsunami Inundation Mapping Efforts has developed a tsunami inundation model for communities at the east end of the Strait of Juan de Fuca. The model uses an initiating event of a magnitude 9.1 earthquake on the Cascadia Subduction Zone off the Pacific Coast. The area modeled includes the highlighted areas on the maps below of the areas in Island, Skagit, and Whatcom Counties.

In the model's simulation, the first tsunami wave would hit the area two hours after the Cascadia Subduction Zone earthquake. Maximum tsunami wave heights are projected to reach 11 feet in the Nooksack River delta near Bellingham, 8 feet at Whitney State Park on Whidbey Island, and 6.5 feet in the Anacortes area.

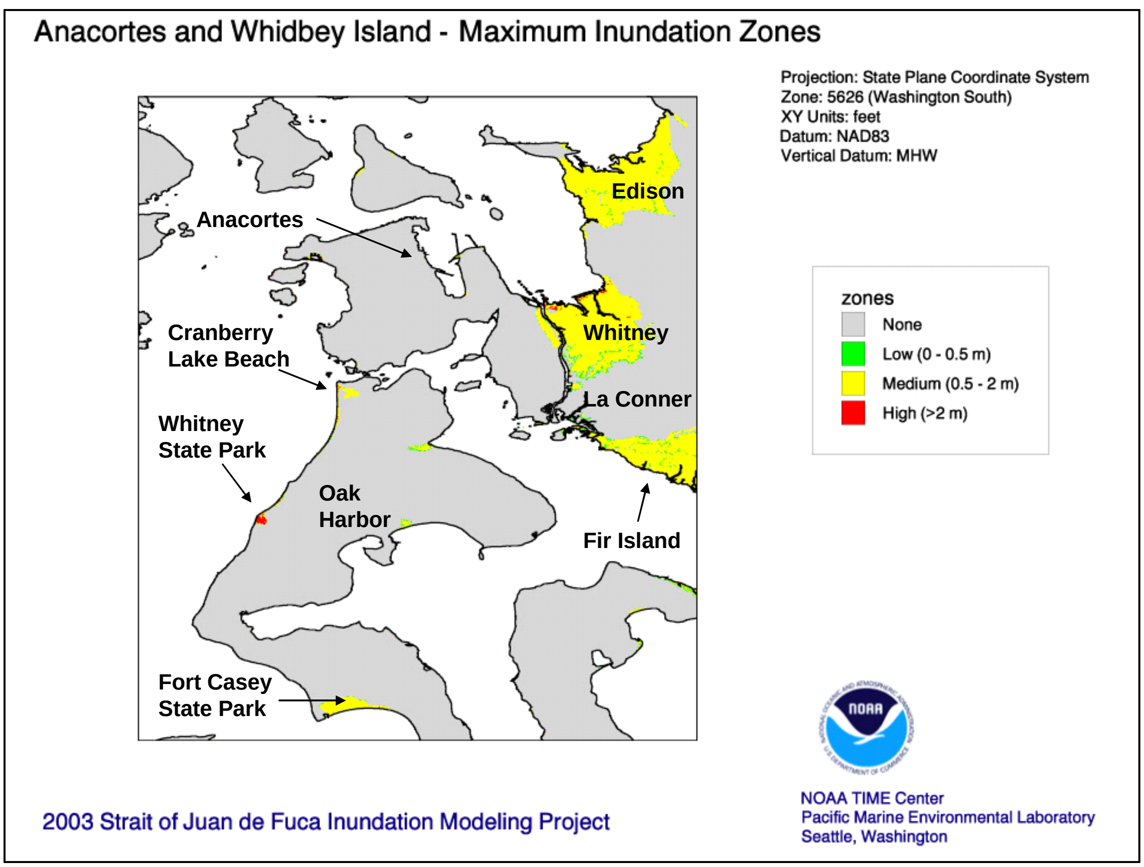
Skagit County – Projected at-risk population: 29,991.

Communities with population at risk: Edison, LaConnor, Fir Island, Whitney.

Island County – Projected at-risk population: 6,988.

Communities with population at risk: Oak Harbor, Cranberry Lake Beach, Fort Casey State Park, Whitney State Park.

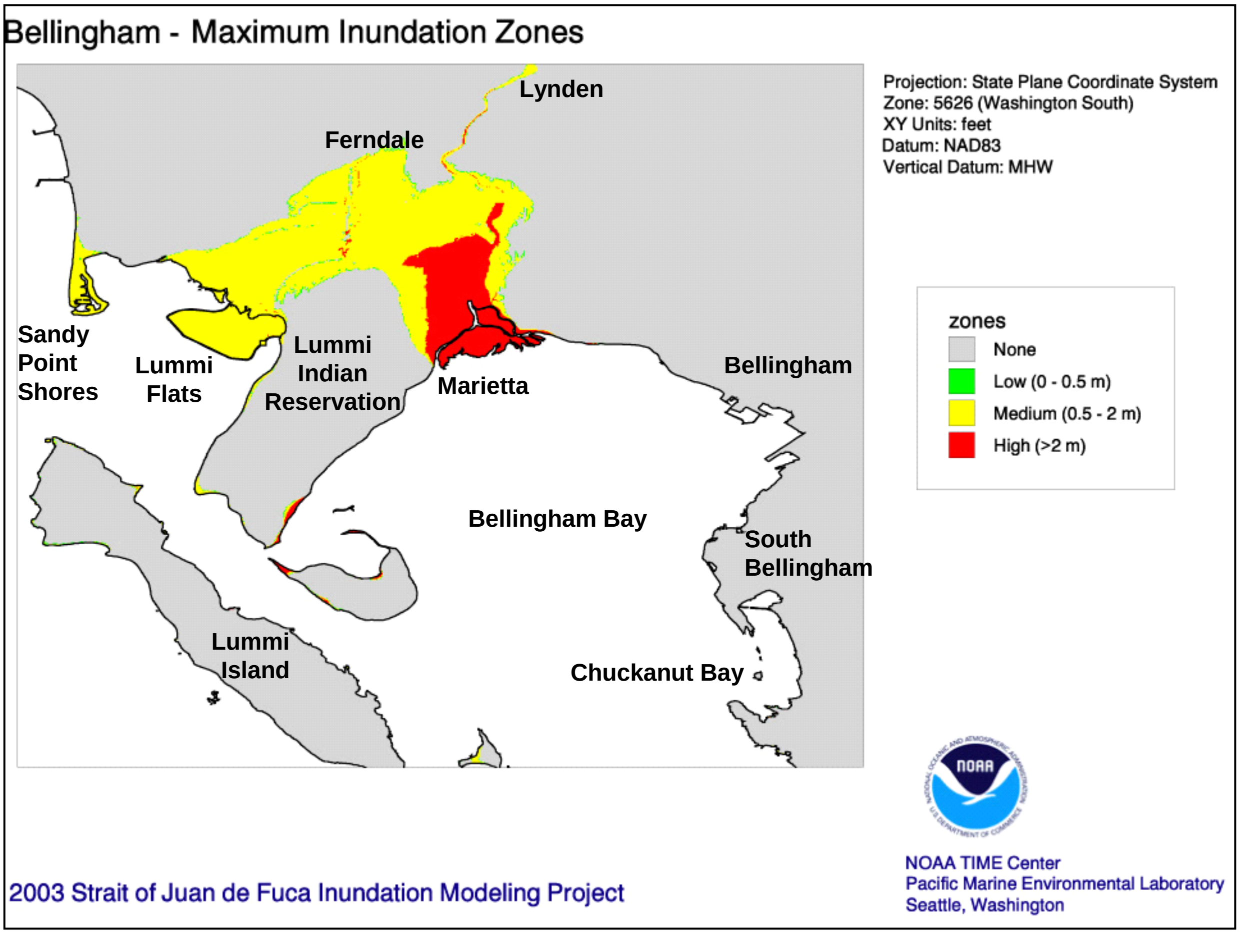
Figure 113 Island and Skagit Counties Tsunami Inundation Map



Whatcom County – Projected at-risk population: 32,845.

Communities with population at risk: Ferndale, Lynden, Marietta, Lummi Indian Reservation, Lummi Flats, Sandy Point.

Figure 114 Whatcom County Tsunami Inundation Map



Tacoma [289]

The National Tsunami Hazard Mitigation Program's Center for Tsunami Inundation Mapping Efforts has developed a tsunami inundation model for Tacoma using as an initiating event a magnitude 7.3 earthquake on the Seattle Fault, and two earthquakes on the Tacoma Fault. The area modeled includes the portions of the Tacoma area highlighted on the map below.

A tsunami from a Seattle Fault earthquake is projected to hit shorelines in Tacoma and Gig Harbor within 20 minutes of the earthquake and reach heights of up to 12 feet. A tsunami generated by a Tacoma Fault earthquake is projected to hit shorelines in Tacoma and Gig Harbor within 10 minutes of the earthquake and reach heights of up to 4 feet.

The projected at-risk population of this area is 55,900.

Communities potentially at risk: Gig Harbor, Tacoma, University Place.

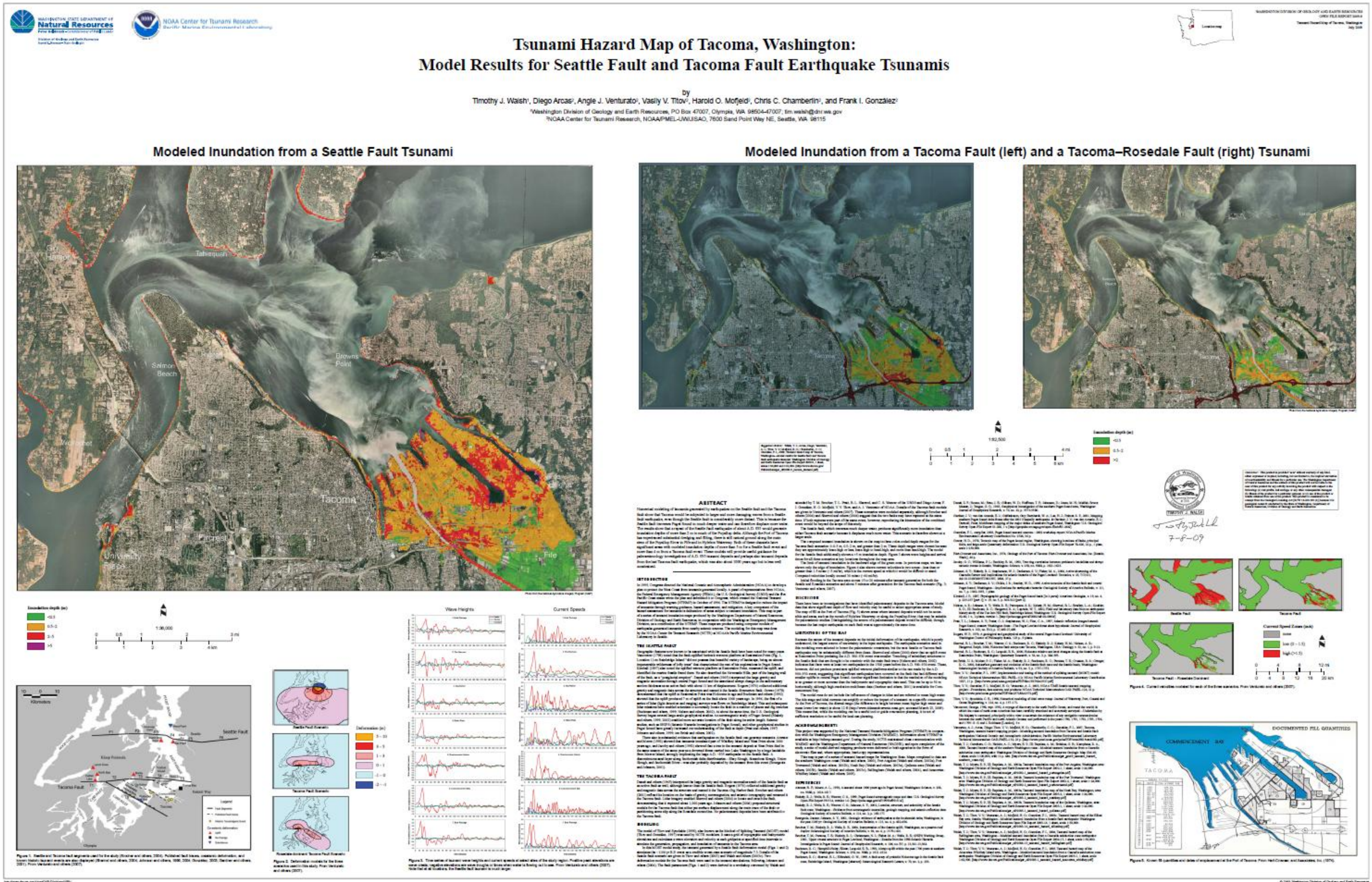


Figure 114 City of Tacoma Tsunami Inundation Map

Puget Sound – Everett to Olympia [290]

Future projects planned by the Washington State Emergency Management's Earthquake, Tsunami and Volcano program and the Department of Natural Resources, Geology and Earth Sciences program through the National Tsunami Hazard Mitigation Program's National Center for Tsunami Research (formerly known as the Center for Tsunami Inundation Mapping Efforts) is to develop tsunami inundation models for the following census designated and incorporated places.

Snohomish County – Projected at-risk population within one kilometer of the coastline: 55,661.

Communities potentially at risk: Edmonds, Everett, Marysville, Mukilteo, Picnic Point-North Lynnwood, Shaker Church, Stanwood, Tulalip Bay, Warm Beach, Weallup Lake, Woodway.

Potential projects include the following areas:

King County (outside Seattle) – Projected at-risk population within one kilometer of the coastline: 45,996.

Communities potentially at risk: Burien, Des Moines, Federal Way, Normandy Park, Vashon.

Kitsap County – Projected at-risk population within one kilometer of the coastline: 61,731.

Communities potentially at risk: Bainbridge Island, Bremerton, Erlands Point, Manchester, Navy Yard City, Parkwood, Port Orchard, Poulsbo, Silverdale, Suquamish, and Tracyton.

Mason County – Projected at-risk population within one kilometer of the coastline: 1,994.

Community potentially at risk: Allyn-Grapeview.

Thurston County – Projected at-risk population within one kilometer of the coastline: 15,939.

Communities potentially at risk: Lacey, Olympia, and Tumwater.

Potential Climate Change Impacts[291,292,293,294]

With the advent of climate change coming into worldwide focus; it is necessary to take into account the potential effects this emerging climate crisis may have on the dangers associated with tsunamis. The research done so far indicates the potential for unusual or more frequent heavy rainfall and flooding is greater is some areas while the potential for drought is predicted in other areas. Landslide frequency is correlated with heavy rainfall and flooding events. Sea level rise may impact inundation areas.

According to a 2005 Governor's report prepared by the Climate Impacts Group titled *Uncertain Future: Climate Change and its Effects on Puget Sound*, from "paleoclimatological evidence, we know that over the history of the earth high levels of greenhouse gas concentrations have correlated with, and to a large extent caused, significant warming to occur, with impacts generated on a global scale." While the report also indicates that the "ultimate impact of climate change on any individual species or ecosystem cannot be predicted with precision," there is no doubt that Washington's climate has demonstrated change.

In July 2007, the Climate Impacts Group launched an unprecedented assessment of climate change impacts on Washington State. *The Washington Climate Change Impacts Assessment* (WACCIA) involved developing updated climate change scenarios for Washington State and using these scenarios to assess the impacts of climate change on the following sectors: agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon, and urban stormwater infrastructure. The assessment was funded by the Washington State Legislature through House Bill 1303.

In 2009, the Washington State Legislature approved the *State Agency Climate Leadership Act* Senate Bill 5560. The Act committed state agencies to lead by example in reducing their greenhouse gas (GHG) emissions to: 15 percent below 2005 levels by 2020; 36 percent below 2005 by 2035; and 57.5 percent below 2005 levels (or 70 percent below the expected state government emissions that year, whichever amount is greater.). The Act, codified in RCW 70.235.050-070, directed agencies to annually measure their greenhouse gas emissions, estimate future emissions, track actions taken to reduce emissions, and develop a strategy to meet the reduction targets. Starting in 2012 and every two years thereafter, each state agency is required to report to Washington State Department of Ecology the actions taken to meet the emission reduction targets under the strategy for the preceding biennium.

Recognizing Washington's vulnerability to climate impacts, the Legislature and Governor Chris Gregoire directed state agencies in 2009 to develop an integrated climate change response strategy to help state, tribal, and local governments, public and private organizations, businesses, and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy*.

Over the next 50 - 100 years, the potential exists for significant climate change impacts on Washington's coastal communities, forests, fisheries, agriculture, human health, and natural disasters. These impacts could potentially include increased annual temperatures, rising sea level, increased sea surface temperatures, more intense storms, and changes in precipitation patterns. Therefore, climate change has the potential to impact the occurrence and intensity of natural disasters, potentially leading to additional loss of life and significant economic losses. Recognizing the global, regional, and local implications of climate change, Washington State has shown great leadership in addressing mitigation through the reduction of greenhouse gases.

At-Risk State Facilities

State Agency facilities identified as being at-risk to tsunami (see table, page 30) were determined using geo-spatial software to match their location to the tsunami inundation zones represented on maps on the previous pages.

Table 85 State Agency Structures At Risk	Vulnerability Assessment

Tsunami:

	# of Facilities	Total Original Cost	Avg. Original Cost	Total Square Feet	Average Sq. Ft.
Owned:	87	$3,945,317	$45,348	209,797	2,411
	# of Essential Facilities	Total Original Cost	Avg. Original Cost	Total Square Feet	Average Sq. Ft.
	4	$102,579	$410,319	12,886	3,221
	# of Facilities	Total Monthly Rent	Avg. Monthly Rent	Total Square Feet	Average Sq. Ft.
Leased:	40	$355,919	$8,897	290,868	7,217
	# of Essential Facilities	Total Monthly Rent	Avg. Monthly Rent	Total Square Feet	Average Sq. Ft.
	4	$75,456	$12,576	44,150	7,358

State owned structure within hazard zone:		

Function of at-risk buildings: Included in the state facilities potentially at-risk to tsunami are the following:

Eight public access points, Lake Whatcom Hatchery and Lake Aberdeen Hatchery operated by the Department of Fish and Wildlife.
Ferry landings in Bremerton and Seattle.
A variety of picnic, comfort, shelter and other facilities at 24 locations operated by the State Parks and recreation Commission.
Seattle Armory and other facilities at Pier 91 in Seattle of the Military Department.
State Patrol detachments in Hoquiam and Raymond.
One state highway considered an emphasis corridor because of its importance to movement of people and freight is potentially at-risk to tsunami as it traverses near vulnerable shorelines:
U.S. Highway 101

State critical facilities at risk within hazard zone:		

Function of at-risk critical facilities: Included in the state facilities potentially at-risk to the direct and indirect impacts of tsunami are the following:

Pump houses, chemical storage, and other facilities of Departments of Fish and Wildlife, Transportation, Ecology, and State Parks and Recreation Commission.
Seattle Armory and other facilities at Pier 91 in Seattle of the Military Department.
State Patrol detachments in Hoquiam and Raymond.
One state highway considered an emphasis corridor because of its importance to movement of people and freight is potentially at-risk to tsunami as it traverses near vulnerable shorelines:
U.S. Highway 101

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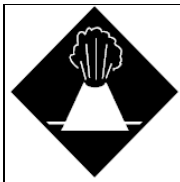
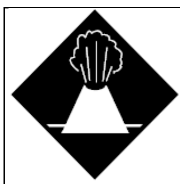
Volcano

	**Frequency**	50+ yrs	10-50 yrs	1-10 yrs	Annually
	People	<1,000	1,000-10,000	10,000-50,000	50,000+
	Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
	Environment	<10%	10-15%	15%-20%	20%+
	Property	<$100M	$100M-$500M	$500M-$1B	$1B+
LAHAR	**Hazard scale**			< Low to High >	

Risk Level – Lahar

Frequency – Lahar incidents do not occur annually.
People – With the early detection and advance of a lahar, significant loss of life can be avoided. Due to the size of the communities in some potential hazard zones for a lahar event, a large number of people may be affected.
Economy – In a catastrophic lahar, the economy can be expected to suffer severely in the beginning stages of the response and recovery. It can also suffer in the end if major infrastructure is damaged and areas affected by the lahar are not available for redevelopment for years to decades as river channels get reestablished and a lot of sediment is transported downstream.
Environment – According to subject matter experts, the threshold for inclusion of this category is unlikely to be met in a single lahar.
Property – State and international statistics indicate that there is the potential for property damage from a large lahar to exceed $1 billion. In some areas of the State the damage could be much larger.
HIVA Risk Classification for Lahar is 2C or Mitigation to Reduce Risk is Required.

	**Frequency**	50+ yrs	10-50 yrs	1-10 yrs	Annually
	People	<1,000	1,000-10,000	10,000-50,000	50,000+
	Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
	Environment	<10%	10-15%	15%-20%	20%+
	Property	<$100M	$100M-$500M	$500M-$1B	$1B+
ASHFALL	**Hazard scale**			< Low to High >	

Risk Level – Ash Fall

Frequency – Volcanic ash fall incidents do not occur annually.
People – An incident of volcanic ash fall is unlikely to result in significant losses of life.
Economy – An incident of volcanic ash fall has the potential to affect the economy of Washington from slightly to severely depending on the amount of ash dispersed over the state and the resources needed to restore normal business operations following such an incident.
Environment – An incident of volcanic ash fall is unlikely to result in the loss of 10% of a single species or habitat.
Property – State and international statistics indicate that there is the potential for property damage from a volcanic ash fall incident to exceed $1 billion.
HIVA Risk Classification for Ashfall is 2C or Mitigation to Reduce Risk is Required.

Summary

The hazard – Washington State has five active volcanoes – Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams. These volcanoes are all capable of generating destructive lahars, ash fall, lava and pyroclastic flows, and debris avalanches. In addition, there are several volcanic fields in southern Washington that could host future eruptions. The phenomenon that poses the greatest threat is ash fall and lahars from the five major volcanoes. Mount Hood in Oregon also poses a threat to communities along the Washington side of the Columbia River. These volcanoes pose a high to very high threat to life, property, the economy, and civil and military aviation from near the volcano to areas hundreds of miles away from the volcanoes' slopes.

Previous occurrences – All five volcanoes have been active in the past 4,000 years. Mount St. Helens has been the only one active in the past 30 years with a massive eruption in 1980, followed by dome building eruptions in the 1980-1986 and 2004-2008. All five volcanoes have generated ash fall and / or lahars in the past 300 years.

Probability of future events – Washington's volcanoes will erupt again, as shown by recent activity at Mount St. Helens. There is a 1 in 500 probability that portions of 2 counties will receive 10 centimeters (4 inches) or more of volcanic ash from any Cascades volcano in any given year, and a 1 in 1,000 probability that parts or all of 3 more counties will receive that quantity of ash. There is a 1 in 100 annual probability that small lahars or debris flows will impact river valleys below Mount Baker or Mount Rainier, and less than a 1 in 1,000 annual probability that the large destructive lahars would flow down the slopes of Glacier Peak, Mount Adams, Mount Baker, and Mount Rainier. There is a much higher probability that significant areas of the State will experience smaller amounts of ash fall.

Jurisdictions at greatest risk – Communities to the northeast, east, and southeast of Mount St. Helens are at greatest risk of receiving damaging ash fall. Communities generally to the west and / or south of the volcanoes are at risk to the impact of damaging lahars.

Special Note - The Cascade Volcano Observatory monitors the Washington State volcanoes for unrest and eruptive behavior and provides an early warning system.

The Hazard[295, 296, 297, 298, 299, 300]

A volcano is a vent in the earth's crust through which magma, rock fragments, gases, and ash are ejected from the earth's interior. Over time, accumulation of these erupted products on the earth's surface creates a volcanic mountain.

Washington State has five major volcanoes in the Cascade Range – from north to south they are Mount Baker, Glacier Peak, Mount Rainier, Mount St. Helens, and Mount Adams. These mountains are composite or strato-volcanoes, a term for steep-sided, often symmetrical cones constructed of alternating layers of lava flows, ash, and other volcanic debris. Composite volcanoes tend to erupt explosively and pose considerable danger to nearby life and property. In contrast, the gently sloping shield volcanoes, such as those in Hawaii, typically erupt non-explosively, producing fluid lavas that can flow great distances from the active vents. Although Hawaiian-type eruptions may destroy property, they rarely cause death or injury. Young lava-flow volcanoes similar to Hawaiian volcanoes form much of the southern part of the Cascades south of Mount St. Helens and Mount Adams to the Columbia River.

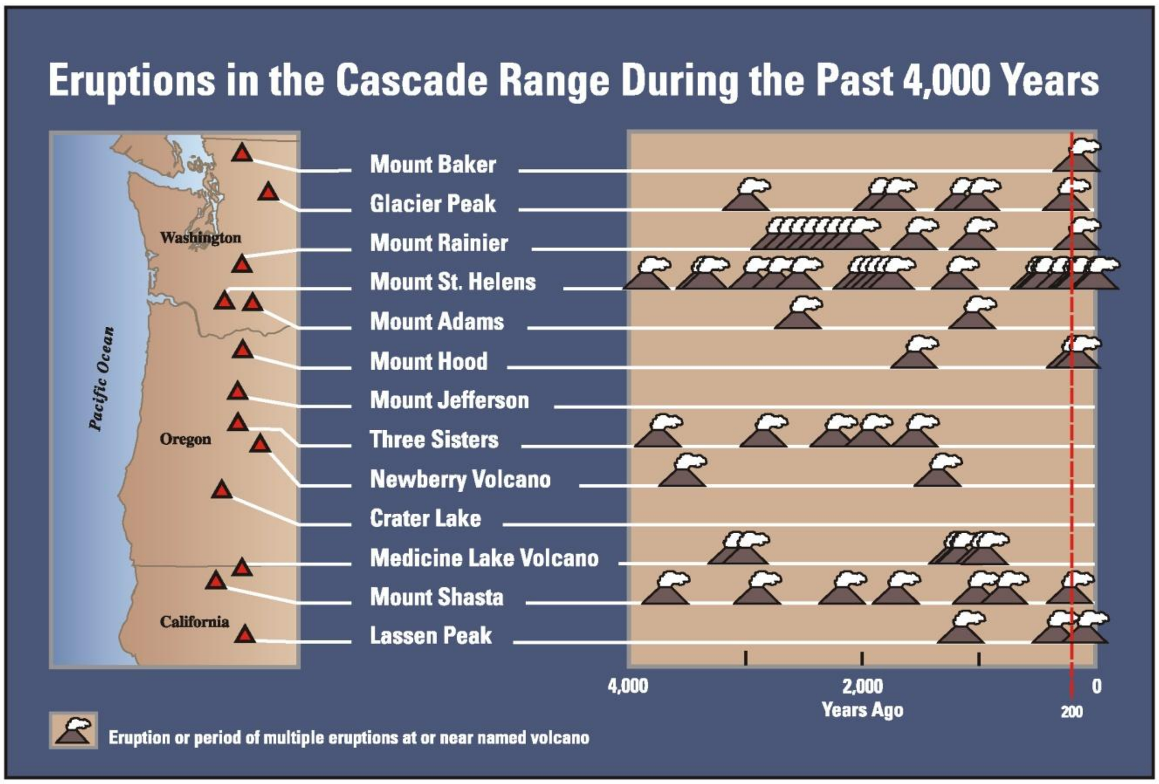


Figure 115 Eruptions in the Cascade Range during the past 4,000 years

Volcanoes can lie dormant for centuries between eruptions making the risk posed by volcanic activity not always apparent. When Cascade Range volcanoes do erupt, high-speed avalanches of hot ash and rock called pyroclastic flows, lava flows, and landslides can devastate areas 10 or more miles away, while huge mudflows of volcanic ash and debris called lahars can inundate valleys more than 50 miles downstream. Falling ash from explosive eruptions can disrupt human activities hundreds of miles downwind, and drifting clouds of fine ash can cause severe damage to the engines of jet aircraft hundreds or thousands of miles away. Because people are moving into areas near these volcanoes at a rapid pace, the state's volcanoes are among the most dangerous in the United States.

Legislation passed by the United States Congress in 1974 established the U.S. Geological Survey (USGS) as the lead agency in charge of providing reliable and timely warnings of volcanic hazards to State and local authorities. Under this Congressional mandate, following the Mount St. Helens eruption of May 1980, the USGS established the Cascades Volcano Observatory, a permanent regional office located in Vancouver, Washington. "Observatory scientists, technicians, and support staff work in partnership with colleagues at other USGS centers, universities, and other agencies to monitor restless volcanoes and provide timely warning of eruptions, assess hazards from volcanoes, including water-related hazards in valleys draining volcanoes, share volcano information with emergency management and planning officials, develop new techniques and methods to better monitor and predict behavior of volcanoes, study volcanic processes, and educate public officials, citizens, and the news media."[301]

The National Volcano Early Warning System (NVEWS) is a proposed national-scale effort by the USGS Volcano Hazards Program and other affiliated partners to ensure that volcanoes are monitored at a level commensurate with the threat that they pose. Of the 169 U.S. volcanoes identified by the NVEWS assessment, four Washington State volcanoes were ranked as very high threat. Specifically, Mount St. Helens was ranked 2^{nd}, Mount Rainier was ranked 3^{rd}, Mount Baker was ranked 11^{th} and Glacier Peak was ranked 12^{th}. Mount Adams was ranked 19^{th} and considered a high threat volcano. Additionally, Oregon's Mount Hood was ranked 4^{th}. It is about 50 miles southeast of Portland and poses some threat to areas of southwest Washington along the Columbia River. Indian Heaven and West Crater volcanic fields in southwest Washington were ranked as low threat volcanoes. This National Volcano Early Warning System seeks to establish enhanced instrumentation and monitoring at targeted volcanoes and a continuously manned volcano watch office to improve the ability to provide rapid, reliable hazard warnings.

Scientists define a volcano as active if it has erupted in recent geologic time or is seismically or geothermally active. Volcanoes commonly repeat past behavior. Typically, volcanoes provide warning signals before they erupt. As magma pushes its way upward, it produces earthquakes, and causes the sides of the volcano to deform. Neither the earthquakes nor the deformation may be apparent to people, but they are detectable with instruments. Heat and gases from the rising magma may cause changes in the temperature, discharge rate, and composition of hot springs and vapors on the volcano and are thus also detectable. In contrast, some landslides and debris flows could occur without specific warning.

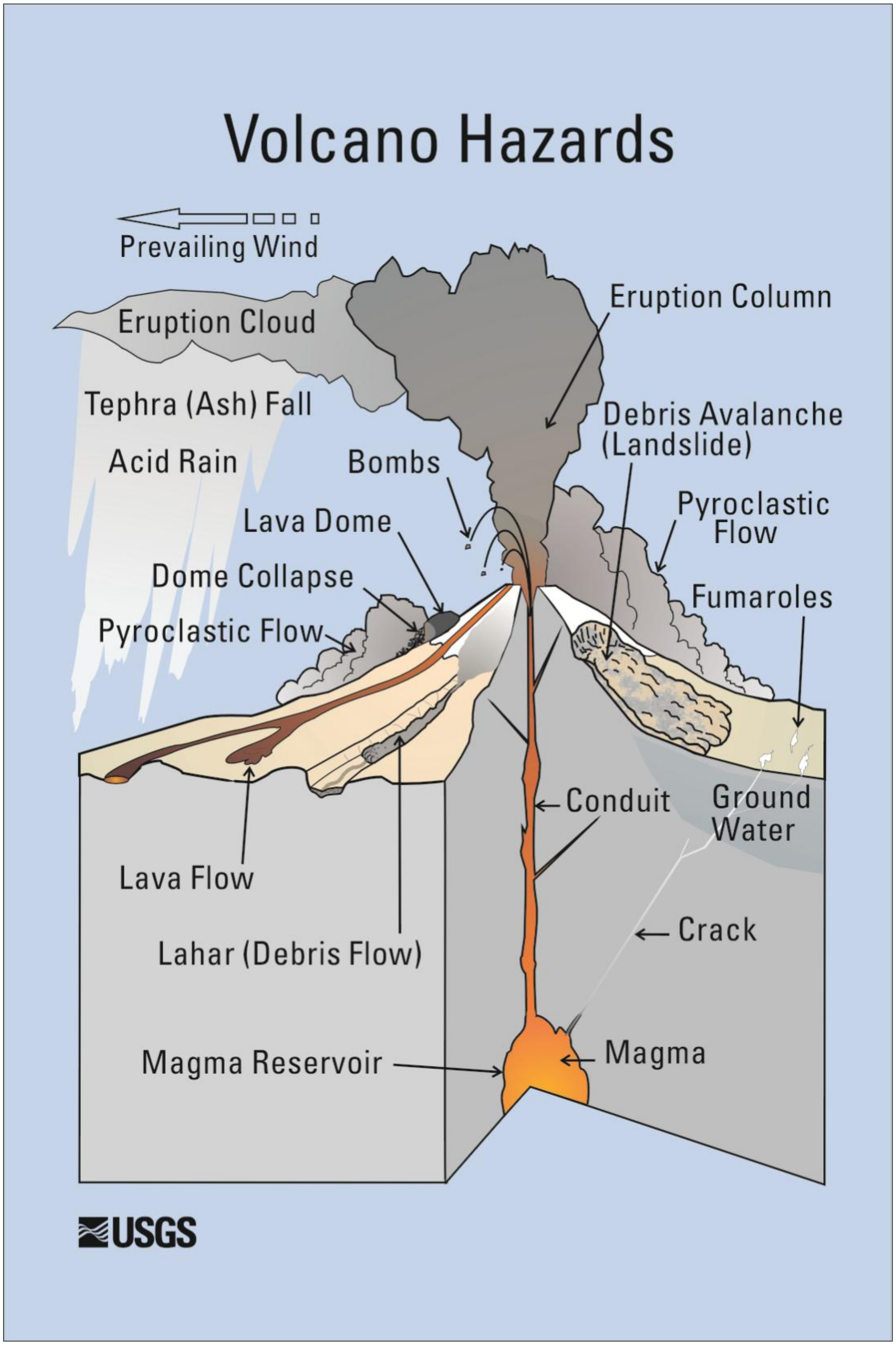


Figure 116 USGS Schematic drawing of various Volcanic Hazards

Long-term, a volcanic eruption can affect an area in a number of ways, including clogging rivers and streams with sediment, smothering agricultural fields, disrupting wildlife habitat and behavior, damaging timber stands and minimizing recreational opportunities. Additionally, transported sediment can affect watersheds for decades by reducing their capacity to carry floodwaters, inhibiting their ability to recover, destabilizing their banks, and filling navigable shipping channels. Recent studies show continued movement of large amounts of sediment through the watersheds below Mount St. Helens more than 30 years after its 1980 eruption.

Among the specific effects of volcanic activity are:

Lava erupted from vents can form lava flows or steep-sided lava domes. Cascade Range lava flows are relatively short, seldom reaching more than 10 miles from the source, and slow moving. The heat of lava flows can melt ice and snow, creating lahars, or start forest or grass fires. They can bury roads and escape routes. Lava domes extruded on steep slopes are subject to collapse, which is one way a pyroclastic flow forms.

Pyroclastic flows are high-speed avalanches of hot ash, rock fragments, and gas that move down the sides of a volcano during explosive eruptions or when the steep edge of a lava flow or part of a lava dome breaks apart and collapses. These flows, which can reach 1,500 degrees F and move up to 100-150 miles per hour, are capable of knocking down and burning everything in their paths. Pyroclastic flows from Cascade volcanoes rarely travel more than 5 to 10 miles from vents. A pyroclastic surge, a more energetic and dilute mixture of searing gas and rock fragments, also travels very fast. Pyroclastic surges move easily up and over ridges, while flows tend to follow valleys.[302] Pyroclastic flows and surges can swiftly melt ice and snow to form lahars that can extend far down valleys.

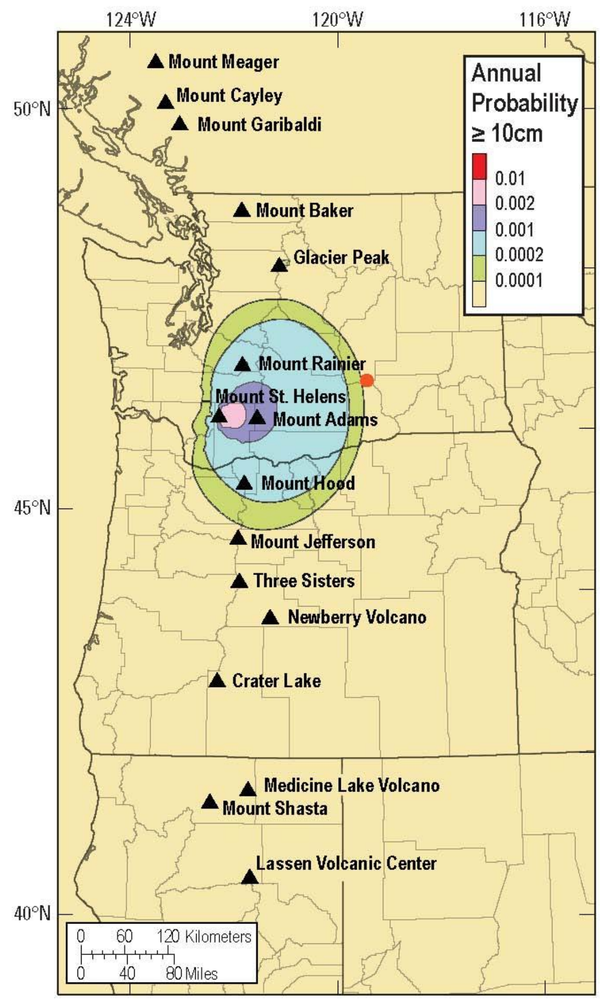
Debris avalanches, a type of landslide consisting of rock, glacial ice, snow, and other debris, cause damage down slope and in valleys. Such avalanches can range in size from small movements of loose debris on the surface of a volcano to massive failures of the entire summit or flanks of a volcano such as occurred during the 1980 eruption of Mount St. Helens. They travel rapidly and can carry large amounts of material; many, especially smaller ones, occur with little or no warning. Wet debris avalanches can transform into lahars, which can flow much farther downstream.

Lahars are a flowing mixture of rock debris and water that originates on the slopes of a volcano. Lahars are also referred to as volcanic mudflows or debris flows.[303] Lahars originate from landslides of water-saturated debris, from the sudden melting of snow and ice by eruptive processes, from heavy rainfall eroding volcanic deposits, or from an outbreak of floodwater from a glacier or from lakes in craters or water dammed by volcanic deposits. Lahars move faster on the steep slopes nearest their source, attaining speeds up to 40 miles per hour or more; large ones can travel more than 50 miles downstream. Close to the volcano, lahars have the strength to rip huge boulders, trees, and buildings from the ground and carry them down valley. Farther downstream, they slow typically to 5-20 miles per hour, deposit material, and can entomb everything in their path in mud. Historically, lahars have been one of the most deadly volcanic hazards.[304]

Tephra falls are produced by explosive eruptions that blast fragments of rock and ash into the air. Large fragments fall to the ground close to the volcano. Small fragments called ash can travel thousands of miles downwind and rise tens of thousands of feet into the air. In some cases, ash can harm the human respiratory system. Heavy ash fall can create darkness. Ash can clog waterways and machinery, cause electrical short circuits, harm mechanical and electronic equipment, and drift into roadways, railways, and runways. Ash can cause jet engines on aircraft to stall. The weight of ash, particularly when it becomes water saturated, can cause structural collapse, especially when it exceeds 10 centimeters or 4 inches depth. Ash resuspended by winds or traffic can be a hazard to animals, people, machinery and transportation systems for months after an eruption.

The most serious tephra hazard in the region is from Mount St. Helens, the most prolific producer of tephra falls in the Cascades during the past few thousand years. The map below provides estimates of the annual probability of tephra fall of 10 centimeters or greater affecting the region from all volcanoes. Probability zones extend farther east of the range because prevailing winds are from the west most of the time. It is very unlikely they would reach densely settled areas: 1 in 5,000 to 1 in 10,000 annual probabilities.

Figure 117 Preliminary probabilistic tephra-hazard map for Pacific Northwest[305]



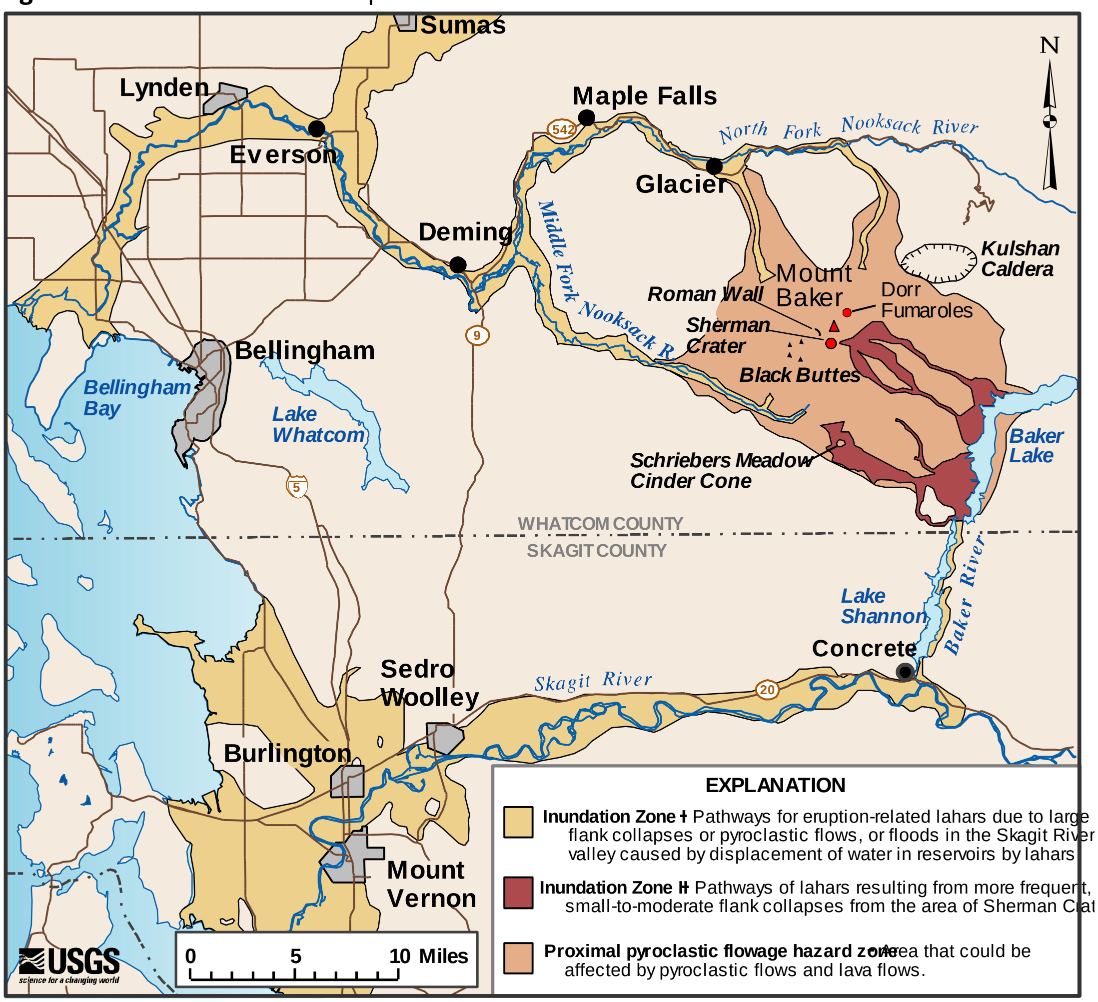
Mount Baker[306, 307]

Mount Baker in Whatcom County erupted in the mid-1800s for the first time in several thousand years. Activity at steam vents in Sherman Crater, near the volcano's summit, increased in 1975 and is still vigorous, but there is no evidence that an eruption is imminent.

Skagit County areas at risk – Burlington, Concrete, Conway, Edison, Hamilton, La Conner, Mount Vernon, and Sedro Woolley, and the valleys of Baker and Skagit Rivers.

Whatcom County areas at risk - Deming, Everson, Ferndale, Glacier, Kulshan, Lynden, Nooksack, and Sumas, valleys of the North Fork Nooksack, Middle Fork Nooksack, and Nooksack Rivers, and the shores of Baker Lake.

Figure 118 Mt. Baker Lahar Map



Hazard zonation map for Mount Baker. Map modified from Gardner and others, 1995; U.S. Geological Survey Open-File Report 95-498.

Mount Baker is not showing signs of renewed activity, but will again; its main hazards are lahars and debris avalanches. These may occur without an accompanying eruption. Mount Baker has not produced large amounts of tephra in the past and probably will not in the future. The annual likelihood of one centimeter or more of tephra falling in eastern Whatcom County, western Okanogan County, and parts of Skagit and Chelan Counties and southern British Columbia from an eruption of Mt. Baker is one chance in 50,000.

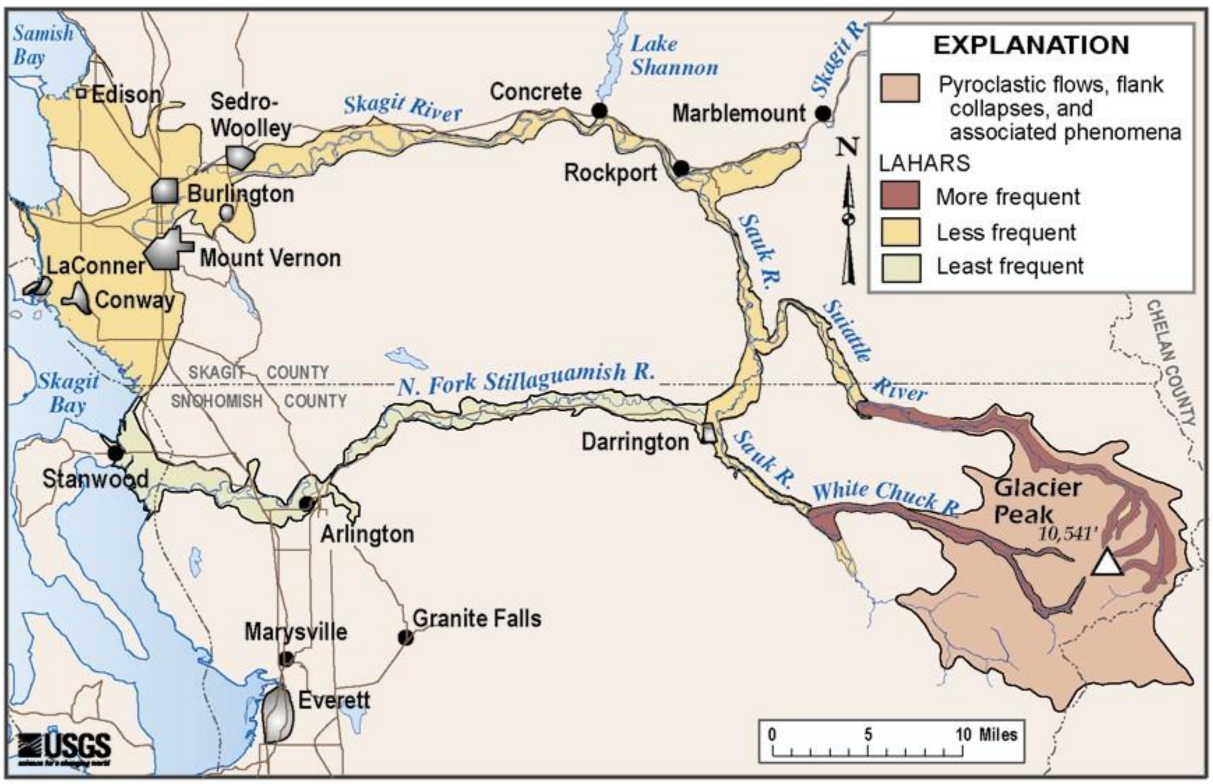
Glacier Peak[308, 309]

Glacier Peak in Snohomish County has erupted at least six times in the past 4,000 years, the last time about 300 years ago with ash and steam eruptions and small lahars. An especially powerful series of eruptions about 13,000 years ago deposited volcanic ash at least as far away as Wyoming.

Skagit County areas at risk – Burlington, Concrete, Conway, Edison, Hamilton, La Conner, Mount Vernon, Rockport, and Sedro Woolley, plus valleys of the Suiattle, Sauk, and Skagit Rivers.

Snohomish County areas at risk – Arlington, Darrington, and Stanwood, plus valleys of the White Chuck, Sauk, and North Fork Stillaguamish Rivers.

Figure 119 Glacier Peak Lahar Map



Areas at risk from lahars, lava domes, pyroclastic flows, and associated phenomena from Glacier Peak . Map modified from R.B. Waitt and others, U.S. Geological Survey Open-File Report 95-499.

Glacier Peak has erupted several times since the Ice Age glaciers retreated 15,000 years ago – most recently around the 18th century. About 13,000 years ago, Glacier Peak hosted a series of explosive eruptions as large as those from Mount St. Helens. Lahars represent the greatest hazard, followed by tephra fall. The annual probability of lahars inundating the Stillaguamish River valley is thought to be less than 1 in 10,000.

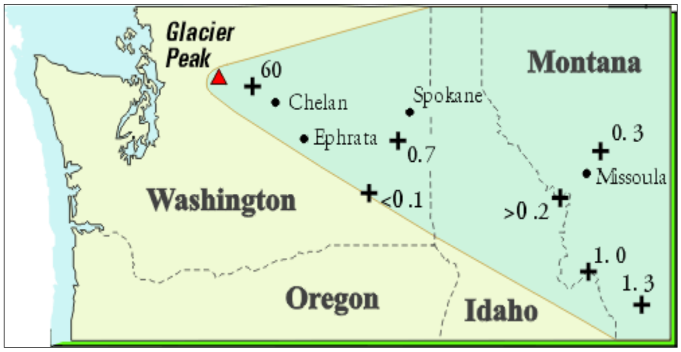


Figure 120 Thickness of Ash from Glacier Peak during a Series of Eruptions about 13,100 years ago. Light blue indicates approximate area covered by ash (spot thickness in inches) during these eruptions.

In future eruptions, lava flows, and ballistic projectiles probably will be contained within 5 to 6 miles of the summit. Pyroclastic flows could travel 13 miles to the west and north of the summit, while pyroclastic surges could travel another three miles farther.

Mount Rainier [310, 311, 312, 313, 314, 315]

Mount Rainier in Pierce County is one of the most hazardous volcanoes in the United States. It has produced several eruptions and numerous lahars in the past 4,000 years. It is capped by more glacial ice than the rest of the Cascades volcanoes combined, and parts of Rainier's steep slopes have been weakened by hot, acidic volcanic gases and water. These factors make this volcano especially prone to landslides and lahars. More than 150,000 people live on deposits of past lahars in river valleys below the volcano.

King County areas at risk – Auburn, Greenwater, Kent, Pacific, Seattle (Duwamish River), and Tukwila, and the valleys of the Duwamish, Green, and White Rivers.

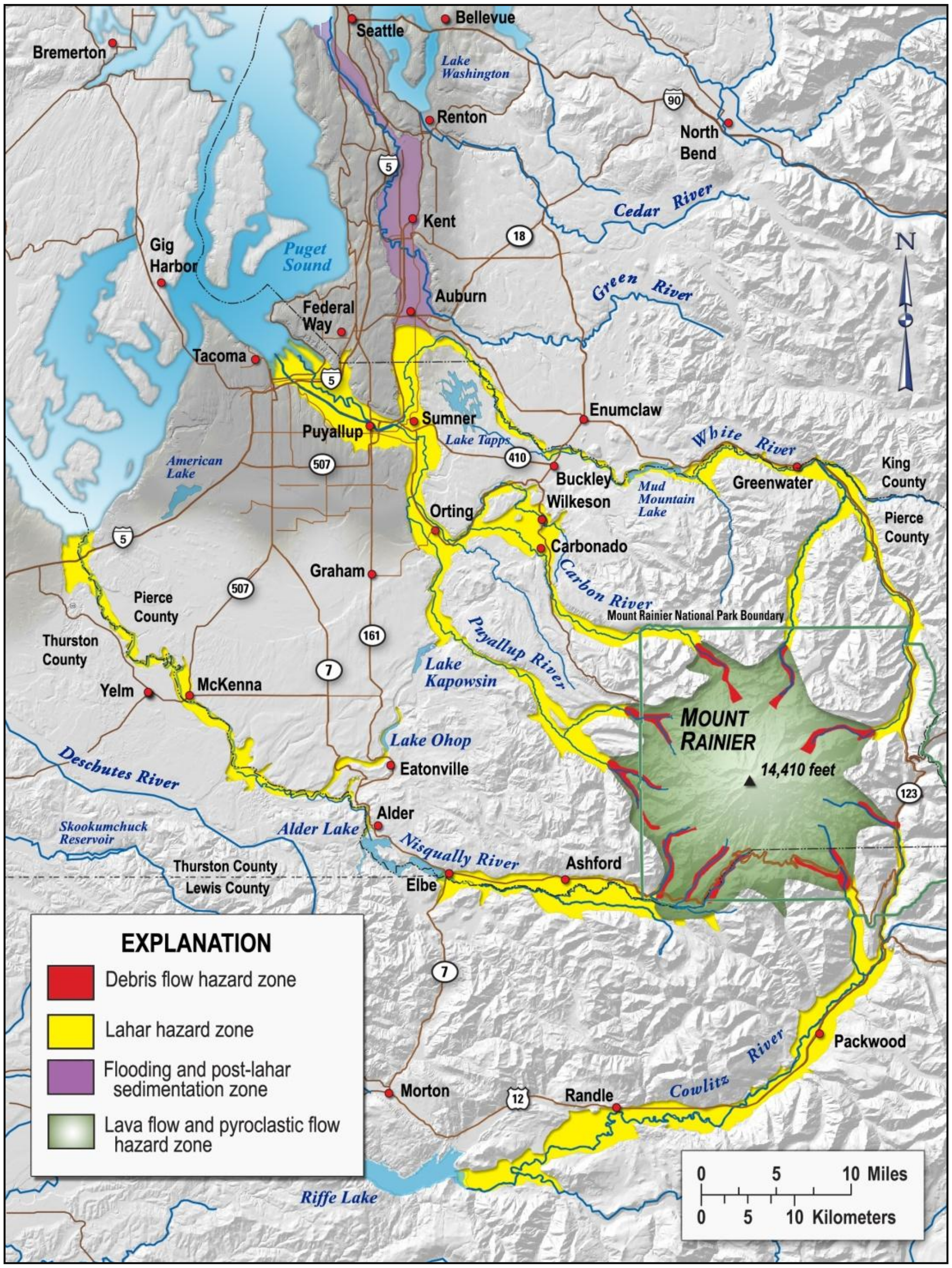
Pierce County areas at risk – Ashford, Buckley, Carbonado, Elbe, Fife, McKenna, Orting, Puyallup, South Prairie, Sumner, and Tacoma, and the valleys of the Carbon, Nisqually, Puyallup, and White Rivers.

Thurston County areas at risk – The Nisqually River valley.

Lewis County areas at risk – Packwood and Randle, and the Cowlitz River valley.

From Mount Rainier, lahars have traveled at a rate of 45-50 miles per hour with depths of over 100 feet were confined in valleys near the volcano, slowing and thinning in the wide and now populated valley floors below. During the past 10,000 years, at least 60 lahars have moved down valleys that begin on Mount Rainier. Lahars are the greatest threat to communities below the volcano. More than 150,000 people live on deposits of old lahars. Lahars that reached the Puget Sound lowland have occurred about every 500 to 1,000 years. Scientists believe there is a one in seven chance that a lahar will reach the Puget Sound lowland in the average human lifespan if future lahars occur at rates similar to those of previous lahars.

Figure 121 Mt. Rainier Lahar Map



Lahar Warning System

Because of the higher level of risk from lahars in the Carbon and Puyallup River valleys, the U.S. Geological Survey and Pierce County in the mid 1990s installed lahar detection and warning systems in the valleys just outside the national park. The system consists of arrays of five acoustic flow monitors along each river that detect the ground vibrations caused by a lahar. Computerized evaluation of data confirms the presence of a flowing lahar and issues an automatic alert to the State EOC, which sends out notices so emergency managers can initiate response measures such as evacuations. This system reduces, but does not eliminate, risk in the lahar pathways.

The U.S. Geological Survey has estimated travel times for a Case I lahar for both the Puyallup and Carbon River basins in the following table. A lahar is projected to reach the following communities in the estimated times after the lahar warning system sounds an alarm.

Table 86 Puyallup River lahar		
Community	Distance from the Source	Estimated Arrival After Alarm
Orting	32 miles	42 minutes
Sumner	40 miles	65 minutes
Puyallup	43 miles	78 minutes
Auburn	46 miles	96 minutes
Commencement Bay, Tacoma	49 miles	108 minutes

Table 87 Carbon River lahar		
Community	Distance from the Source	Estimated Arrival After Alarm
Carbonado	24 miles	12 minutes
Wilkeson	27 miles	18 minutes
Orting	32 miles	42 minutes

Larger lahars would reach downstream communities more quickly; smaller ones more slowly.

In future eruptions, pyroclastic flows, pyroclastic surges, lava flows, and ballistic projectiles probably will not extend beyond the national park boundaries. The annual probability of pyroclastic flows, pyroclastic surges, lava flows, and ballistic projectiles affecting some part of the area is less than 1 percent.

Mount St. Helens[316, 317, 318]

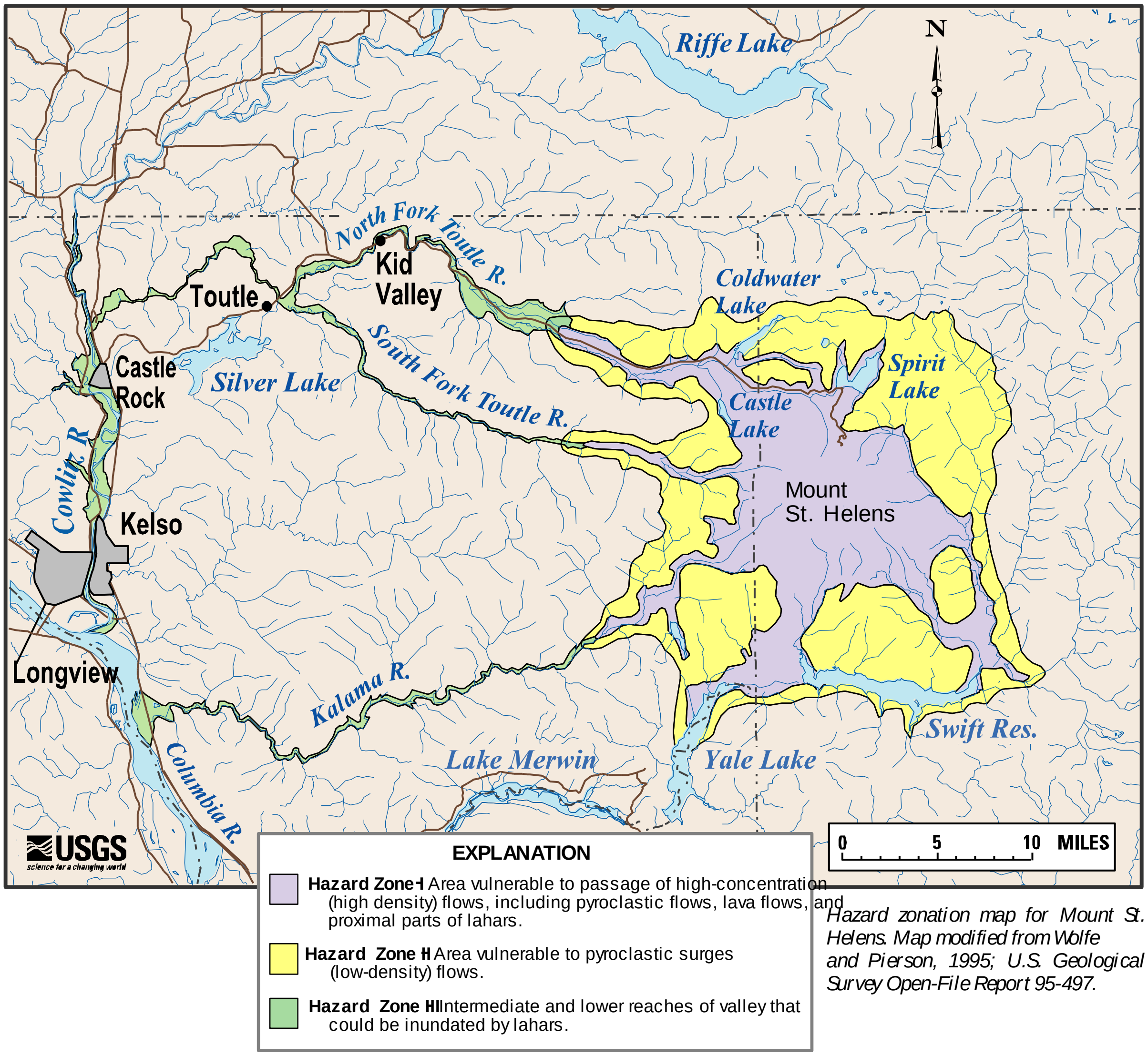
Mount St. Helens in Skamania County is the youngest, most frequently active, and often the most explosive volcano in the Cascades. During the past 4,000 years, it has produced many lahars and a wide variety of eruptive activity, from relatively quiet outflows of lava to explosive eruptions much larger than the one on May 18, 1980.

Cowlitz County areas at risk - Castle Rock, Kelso and Longview, and the valleys of the Cowlitz, Kalama, Lewis, and Toutle Rivers.

Skamania County areas at risk – unincorporated areas.

Mount St. Helens remains an active and dangerous volcano. In the last 515 years, it produced four major explosive eruptions and dozens of lesser eruptions. One of those, in 1480, was about five times larger than the May 18, 1980 eruption; even larger eruptions have occurred during Mount St. Helens' lifetime.

Figure 122 Mount St. Helens Lahar Map



Hazard zonation map for Mount St. Helens. Map modified from Wolfe and Pierson, 1995; U.S. Geological Survey Open-File Report 95-497.

Lahars are a greater threat to life and property in communities of the Cowlitz and lower Toutle River drainages than any other volcanic phenomenon. Previous lahars, including those from the May 18, 1980 eruption, traveled 30 to 60 miles, often reaching the Columbia River via the Toutle, Kalama, or Lewis Rivers. Non-eruption events such as intense storm runoff over erodible sediment, landslides, or failure of the Castle Lake impoundment can generate lahars. Neither a large debris avalanche nor a major lateral blast like those of May 18, 1980 is likely now that a deep, open crater has formed.

Based on the behavior of lahars from the May 1980 eruption, estimated travel times have been developed for lahars traveling down the North Fork Toutle River valley, and the South Fork Toutle River, Pine Creek, Muddy River, and Kalama River valleys:

Table 88 Distance from Mount St. Helens	Projected Lahar Travel Time	
	N. Fork Toutle River	**S. Fork Toutle River, Pine Creek, Muddy River, Kalama River**
20 Kilometers (12.4 miles)	37 minutes	**30 minutes**
40 kilometers (24.9 miles)	1hour, 8 minutes	**1 hour, 21 minutes**
60 kilometers (37.3 miles)	3 hours, 27 minutes	**2 hours, 20 minutes**
80 kilometers (49.7 miles)	4 hours, 43 minutes	**3 hours, 31 minutes**
100 kilometers (62.1 miles)	**8 hours, 50 minutes**	**5 hours, 12 minutes**

Mount St. Helens repeatedly has produced voluminous tephra. While tephra from the May 18, 1980 eruption covered about 22,000 square miles, the lethal impact from falling tephra is likely only in the immediate vicinity of Mount St. Helens; damaging impacts from falling tephra, were seen hundreds of miles away.

The calculated annual probability that four or more inches of tephra from a large eruption will fall as far as 40 miles directly east of Mount St. Helens is about 1 in 500. The calculated annual probability that such an eruption would deposit four or more inches 40 miles directly west of Mount St. Helens is less, between 1 and 2 in 10,000.

Mount Adams[319, 320]

Mount Adams in Yakima and Skamania Counties has produced few eruptions during the past several thousand years. This volcano's most recent activity was a series of small eruptions about 1,000 years ago followed by a debris avalanche and lahar that inundated part of the Trout Lake lowland less than 500 years ago.

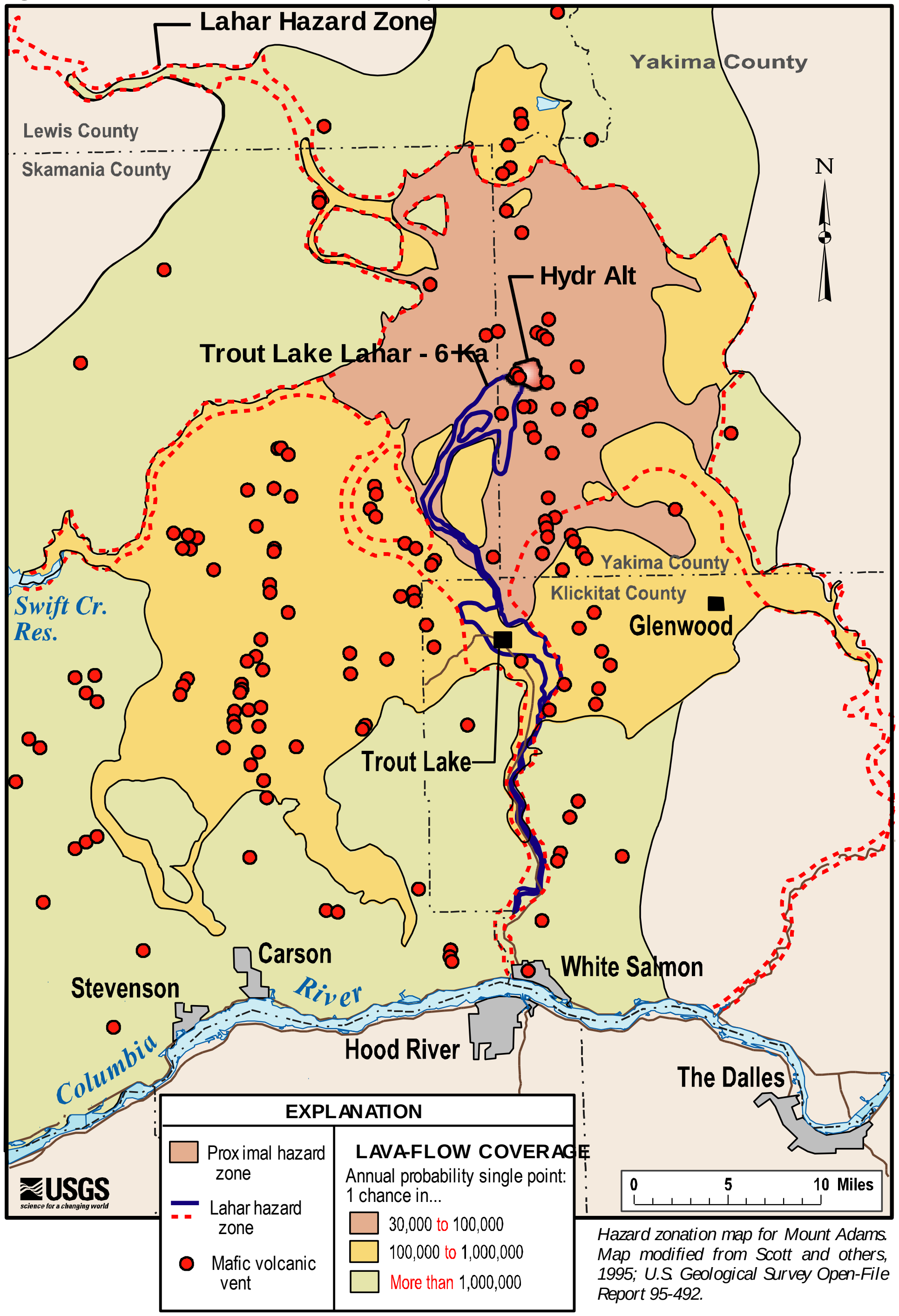
Klickitat County areas at risk – Lyle, Trout Lake and the lower White Salmon River valley.

Skamania County areas at risk – Carson, Stevenson, and unincorporated areas in the eastern part of the county including valleys of the Cispus and Lewis Rivers.

Numerous communities along the Columbia River in both Klickitat and Skamania Counties lie in the local proximal hazard zone for lava flow.

Lewis County areas at risk – Unincorporated areas of the Cispus River valley, including Riffe Lake. Yakama Nation and Yakima County areas at risk including unincorporated areas of the far western reaches.

Figure 123 Mount St. Helens Lahar Map



Mount Adams dominates a volcanic field in Lewis, Skamania, Yakima, and Klickitat counties of south-central Washington. The volcano has erupted little during the past 10,000 years; it is less active than neighboring Mounts St. Helens, Rainier, and Hood. Highly explosive eruptions of Mount Adams have been rare. Much of the hazard area for eruptive events lies in the Gifford Pinchot National Forest or remote areas of the Yakama Indian Reservation. Areas of greatest concern are located along the channels and floodplains of the White Salmon, Klickitat, Lewis, and Cispus Rivers that are subject to lahars.

The dominant type of eruption at Mount Adams, as well as in the adjacent volcanic fields, produces lava flows, or streams of molten rock. Several significant lava flows have occurred in the region during the past 10,000 years and most of them traveled between 8 and 20 miles. The annual probability of a lava flow occurring on Mount Adams or its lower flanks is about 1 in 1,000, but because a lava flow would only cover part of the area, the annual probability of a given point being covered is much less, about 1 in 30,000 to 1 in 100,00.

Rivers that drain the north and northwest flanks of Mount Adams can discharge sediment from lahars into Swift Reservoir on the Lewis River and Riffe Lake on the Cowlitz River. Streams that drain the southwest and east flanks can deliver sediment to the Columbia River and could affect navigation and hydroelectric operations at Bonneville Dam. Lahars large enough to reach the Trout Lake lowland have annual probabilities of about 1 in 100 to 1 in 1,000. A lahar the size of the Trout Lake lahar has an annual probability of about 1 in 1,000 to 1 in 10,000, whereas a lahar of sufficient magnitude to inundate the entire length of one or more valleys has not occurred in the last 10,000 years and has an annual probability less than 1 in 10,000.

Tephra from Mount Adams does not pose a serious or widespread hazard; eruptions have blanketed only areas within a few miles from the volcano with ash fall of several inches. Thinner deposits probably extended tens of miles father.

Mount Hood, Oregon[321, 322]

Clark County areas at risk – Camas and Washougal, and nearby unincorporated areas.

Klickitat County areas at risk – Unincorporated areas near White Salmon.

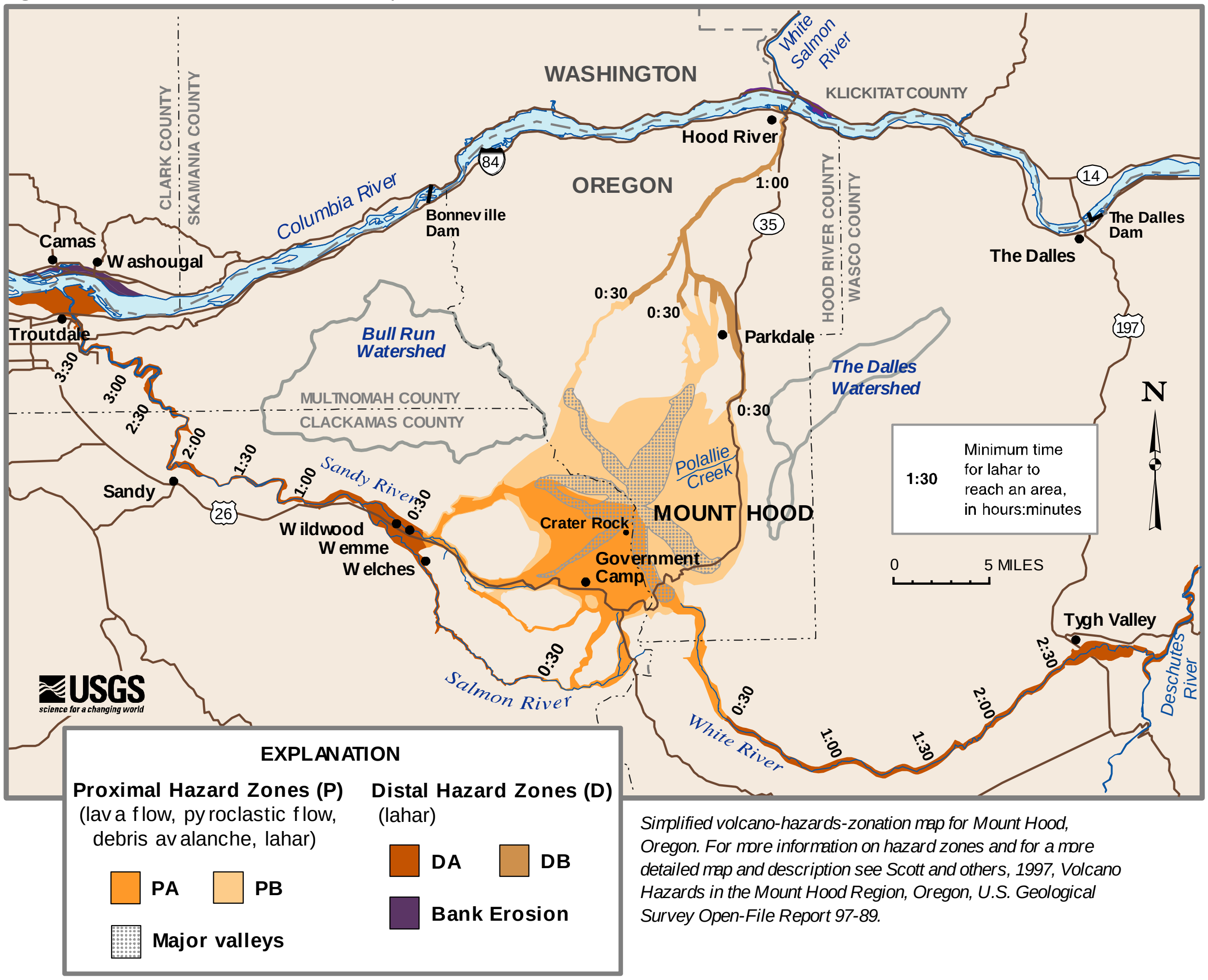
Skamania County areas at risk – Stevenson, and unincorporated areas.

More than 100,000 years ago, a much larger debris avalanche and related lahar flowed down the Hood River, crossed the Columbia River, and flowed several kilometers up the White Salmon River in Klickitat County. Scientists believe this deposit temporarily dammed the Columbia River.

Future lahars and eruption-induced sedimentation are likely to build the Sandy River delta farther out into the Columbia River and narrow the existing channel, which could lead to progressive bank erosion and inundation of land in the Camas-Washougal area of Clark County. The 30-year probability that lahars will inundate areas of the Sandy River valley is about 1 in 15 to 1 in 30.

Mount Hood is a relatively modest tephra producer, and much of the tephra fall would occur east of the mountain due to prevailing winds.

Figure 124 Mount Hood Lahar Map



Simplified volcano-hazards-zonation map for Mount Hood, Oregon. For more information on hazard zones and for a more detailed map and description see Scott and others, 1997, Volcano Hazards in the Mount Hood Region, Oregon, U.S. Geological Survey Open-File Report 97-89.

Jurisdictions Threatened and Vulnerable to Volcanic Hazards

The jurisdictions vulnerable to lava flow, lahars, and ash fall from volcanic eruptions come from U.S. Geological Survey hazard reports and hazard zone maps published for each volcano. The fourteen counties threatened are listed below in the table.

Table 89 County Jurisdictions Vulnerable to Volcanic Hazards				
Chelan (ash)	Clark (ash, lahar)	Cowlitz (ash, lahar)	King (ash, lahar)	**Kittitas (ash)**
Klickitat (ash, lahar)	Lewis (ash, lahar)	Pierce (ash, lahar)	Skagit (lahar)	**Skamania (ash, lahar)**
Snohomish (lahar)	**Thurston (lahar)**	**Whatcom (lahar)**	**Yakima (ash)**	

Jurisdictions at risk to lava flow and lahar are identified in the table below with annual probabilities. Once a volcano becomes restless or begins to erupt, the probability for lahars and other effects increases greatly over these long-term averages.

Table 90 Annual Probability of Occurrence of a Lahar		
Volcano	Lahar	**Annual Probability**
Glacier Peak	Inundates Lower Suiattle River	**1-2 in 1,000**
	Reaches Puget Sound	**1-2 in 10,000**
	Inundates Stillaguamish River	**< 1 in 10,000**
Mount Adams	Reaches Trout Lake	**1 in 100 to 1 in 1,000**
Mount Baker	Debris Flows along flanks	**≥1 in 100**
	Inundates Nooksack River	**≤1 in 500**
	Reaches Puget Sound	**1 in 14,000**
Mount Rainier	Debris Flows within National Park	**≥1 in 100**
	Inundates Nisqually River (National Lahar)	**1 in 100 to 1 in 500**
	Reaches Puget Sound lowlands (Electron Mudflow)	**1 in 500 to 1 in 1,000**
	Reaches Puget Sound (Osceola Mudflow)	**≤ 1 in 10,000**
Mount St. Helens	**Not calculated due to 1980 eruption**	
Mount Hood	Inundates Sandy River	**≥1-2 in 1,000**
Source: U.S. Geologic Survey volcano hazard reports, 1995 and 1998 These probabilities are based on mean rates (length of time divided by number of events) but events are clustered in time		

Jurisdictions at-risk to ash fall are those with a 1 in 1,000 chance of receiving 10 centimeters (4 inches) of ash fall each year on the map below. However, ash fall considerably less than 10 cm is still a nuisance and capable of producing a lot of problems for jurisdictions. Since the prevailing winds are westerly, many eastern Washington counties will have to deal with some level of ash fall in the future.

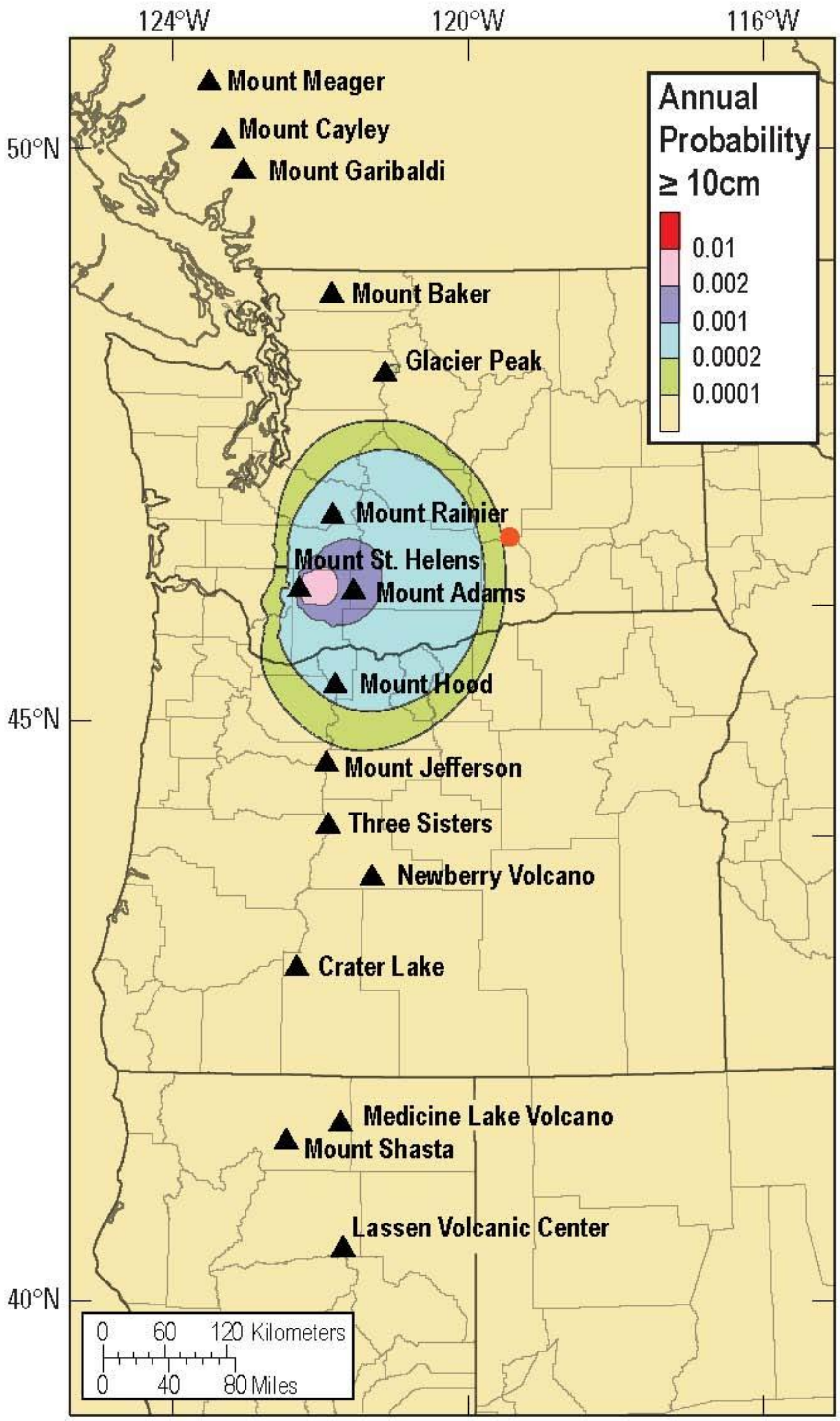


Figure 125 Volcanoes in the Pacific Northwest

Potential Climate Change Impacts [323,324,325,326]

With the advent of climate change coming into worldwide focus; it is necessary to take into account the potential effects this emerging climate crisis may have on the dangers associated with volcanoes. The research done so far indicates the potential for unusual or more frequent heavy rainfall and flooding is greater is some areas while the potential for drought is predicted in other areas. Landslide frequency is correlated with heavy rainfall and flooding events.

Recognizing Washington's vulnerability to climate impacts, the Legislature and Governor Chris Gregoire directed state agencies in 2009 to develop an integrated climate change response strategy to help state, tribal, and local governments, public and private organizations, businesses, and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy*.

Over the next 50 - 100 years, the potential exists for significant climate change impacts on Washington's coastal communities, forests, fisheries, agriculture, human health, and natural disasters. These impacts could potentially include increased annual temperatures, rising sea level, increased sea surface temperatures, more intense storms, and changes in precipitation patterns. Therefore, climate change has the potential to impact the occurrence and intensity of natural disasters, potentially leading to additional loss of life and significant economic losses. Recognizing the global, regional, and local implications of climate change, Washington State has shown great leadership in addressing mitigation through the reduction of greenhouse gases.

At-Risk State Agency Facilities

State Agency facilities identified as being at-risk to lahar were determined using geo-spacial software to match their location to the lahar hazard zone identified by the U.S. Geological Survey. The hazard zones chosen were for the worst-case, largest lahars possible.

Table 91 State Agency Structures At Risk	Vulnerability Assessment	
Number and Function of Buildings	Approx. Square Footage of Facilities	Approx. Value of Owned and Leased Structures and Building Contents
Total at-risk buildings: 859 state facilities were identified as being in the lahar hazard zone potentially at-risk to direct damage or to the indirect impacts of lahar (utility services reductions, transportation restrictions, etc.).	6,368,709	$1,273,741,800
Function of at-risk buildings: Included in the state facilities potentially at-risk to the direct and indirect impacts of a worst-case lahar are the following: Campuses of the Rainier School for individuals with developmental disabilities, and of the Washington Soldiers Home and Colony. Arlington, Kendall Creek, Fallart Creek, North Toutle, Voights Creek, Soos Creek, and Klickitat hatcheries of the Department of Fish and Wildlife. Picnic, comfort, shelter, and other facilities at four parks operated by the State Parks and Recreation Commission, and a number of public access areas operated by the Department of Fish and Wildlife. Campuses of Skagit Valley College; Northwest Washington and Puyallup Research and Extension		

Centers operated by Washington State University; and Pack Forest operated by the University of Washington. Five weigh stations and detachment offices in Enumclaw and Burlington of the Washington State Patrol.		
Total at-risk critical facilities: 119 state critical facilities were identified as being in the lahar hazard zone potentially at-risk to direct damage or to the indirect impacts of lahar (utility services reductions, transportation restrictions, etc.).	970,570	$194,114,000
Function of at-risk critical facilities: Included in the state facilities potentially at-risk to the direct and indirect impacts of a worst-case lahar are the following: Pump houses, chemical storage, power plants and emergency generators, and other facilities at state parks, state fish hatcheries, transportation department installations, WSU research centers, campuses of the Rainier School and Washington Soldiers Home, . Five weigh stations and detachment offices in Enumclaw and Burlington of the Washington State Patrol.		

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Wildland Fire

	Frequency	50+ yrs	10-50 yrs	1-10 yrs	Annually
	People	<1,000	1,000-10,000	10,000-50,000	50,000+
	Economy	1% GDP	1-2% GDP	2-3% GDP	3%+ GDP
	Environment	<10%	10-15%	15%-20%	20%+
	Property	<$100M	$100M-$500M	$500M-$1B	$1B+
Fire	**Hazard scale**			< Low to High >	

Risk Level

Frequency – One or more wildland fires occur in Washington every year.

People – The number of lives lost to wildland fires in Washington does not meet the minimum threshold for this category.

Economy – While the local economy where the wildland fire occurs may be affected, the affect that wildland fires have on the economy of Washington does not meet the minimum threshold for this category.

Environment – While the damage to forest fires can be significant, the potential for 10% of a single species or habitat to be destroyed by such a fire is highly unlikely.

Property – Past U.S. wildland fires indicate that the amount of property damage due to a wildland fire can exceed $100 million dollars.

HIVA Risk Classification for Wildfire is 3A or Mitigation to Reduce Risk is Required.

Note: The discussion of the Urban Fire Hazard begins on page 365.

Summary

The hazard – Wildland fire burns approximately 23,000 acres of state-owned or protected land annually. The cost of wildland fire on these lands is more than $28 million annually in firefighting and damage to timber, habitat, and property.

Previous occurrences – Washington has a long history of both small and very large fires. Some fires can reach 100,000 acres or more, which has occurred seven times since 1902. The state has experienced 34 fires of at least 2,500 acres on state-owned or protected land since 1992. The most recent large fire was Taylor Bridge in 2012, which burned 23,500 acres, destroyed 61 homes and 211 outbuildings.

Probability of future events – Approximately 800 wildland fires occur each year on state-owned or protected land; most are small and less than one acre in size. Approximately 70 percent occur in Eastern Washington. Humans cause most wildland fires. The wildland fire season usually begins in early July and typically culminates in late September, but fires have occurred in every month of the year.

Jurisdictions at greatest risk – The Washington Department of Natural Resources has identified 221 communities in 34 counties at greatest risk to wildland fire, based on criteria in the wildfire hazard severity analysis developed by the National Fire Protection Association (NFPA).

The hazard map represents the communities in Washington at risk to a wildland-urban interface (WUI) fire. The WUI is defined by the NFPA as the "area where improved property and wildland fuels meet at a well-defined boundary." More information on the WUI can be found later in this section.

The following map was created by the Washington State Department of Natural Resources (DNR) and classifies risk of a WUI fire between moderate to extreme.

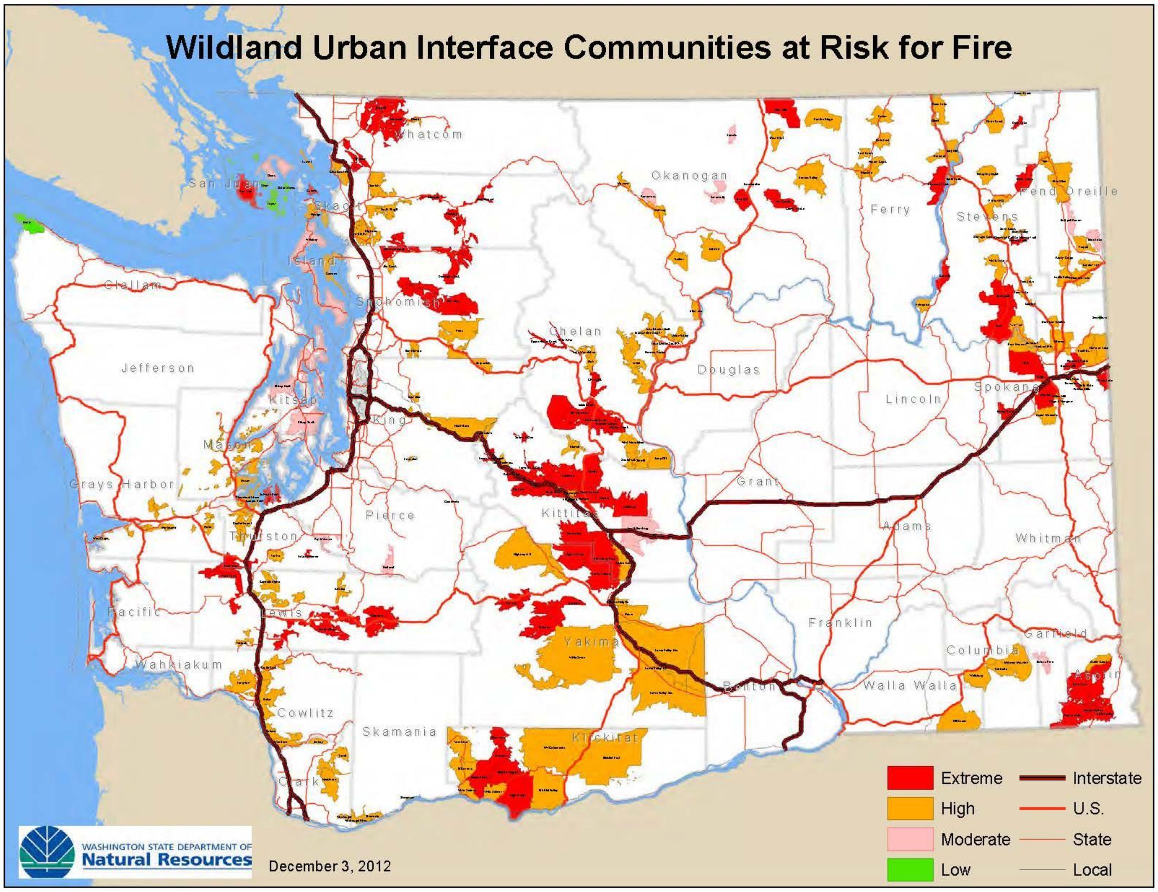


Figure 126 Hazard Area Map Wildland-Urban Interface Communities at Risk for Fire. Washington Department of Natural Resources (DNR) 2012

The Hazard[327],331F[328],332F[329],333F[330],334F[331],335F[332],336F[333],337F[334]

Wildland fires are fires caused by nature or humans that result in the uncontrolled destruction of forests, brush, field crops, grasslands, and real and personal property.

The wildland fire season in Washington usually begins in early July and typically culminates in late September with a moisture event; however, wildland fires have occurred in every month of the year. Drought, snow pack, and local weather conditions can expand the length of the fire season. The early and late shoulders of the fire season usually are associated with human-caused fires. Lightning generally is the cause of most fires in the peak fire period of July, August, and early September.

Short-term loss caused by a wildland fire can include the destruction of timber, wildlife habitat, scenic vistas, and stormwater retention plus closure to recreation, hunting, and fishing opportunities. Long-term effects include smaller timber harvests, reduced access to affected recreational areas, and destruction of cultural, economic and community infrastructure resources.

The Washington Department of Natural Resources protects 2.8 million acres of state-owned land and 10 million acres of land in private ownership through legislative directive [RCW 76.04].

The department fights about 800 wildland fires per year across the state of which nearly 70 percent are in Eastern Washington. Most of these fires are small and are usually extinguished while they are less than one acre in size. People start most wildland fires on state lands through arson, recreational fires that get out of control, smokers' carelessness, debris burning, fireworks and children playing with fire. Lightning starts most fires on federally protected lands.

Wildland fires can spread to more than 100,000 acres and may require thousands of firefighters and several months to extinguish. Federal, state, county, city, and private agencies and private timber companies provide fire protection and firefighting services on forestlands in Washington State.

Factors that influence wildland fire[335]

A fire needs three elements in the right combination to start– a heat source, fuel, and oxygen. How a fire behaves primarily depends on the characteristics of available fuel, weather conditions, and terrain.

- Fuel:
  - Lighter fuels such as grasses, leaves, and needles quickly expel moisture and burn rapidly, while heavier fuels such as tree branches, logs, and trunks take longer to warm and ignite.
  - Snags and hazard trees – those that are diseased, dying, or dead – are larger west of the Cascades, but more prolific east of the Cascades. In 2012, approximately 1.2 million acres of the state's 21 million acres of forestland contained trees killed or defoliated by forest insects and diseases.

- Weather:
  - West of the Cascades, strong, dry east winds in late summer and early fall produce extreme fire conditions. East wind events can persist up to 48 hours with wind speed reaching 60 miles per hour; these winds generally reach peak velocities during the night and early morning hours.
  - East of the Cascades, summer drying typically starts in mid June and runs through early September, with drought conditions extending this season. Passage of a dry, cold front

through this region can result in sudden increase in wind speeds and a change in wind direction affecting fire spread.
    - Thunderstorm activity, which typically begins in June with wet storms, turns dry with little or no precipitation reaching the ground as the season progresses into July and August. Thunderstorms with dry lightning are more prevalent in Eastern Washington.

- Terrain:
    - Topography of a region or a local area influences the amount and moisture of fuel.
    - Barriers such as highways and lakes can affect spread of fire.
    - Elevation and slope of landforms – fire spreads more easily as it moves uphill than downhill.

The peak burning period of a fire generally is between 1 p.m. and 6 p.m. Wildland fires can take on a life of their own when there is plenty of heat and fuel. They can create their own winds and weather including generating hurricane force winds of up to 120 miles per hour. Fires can heat fuels in their path, drying them out, and making them easier to ignite and burn.

Figure 127 Table Mountain Fire creating its own weather, DNR 2012

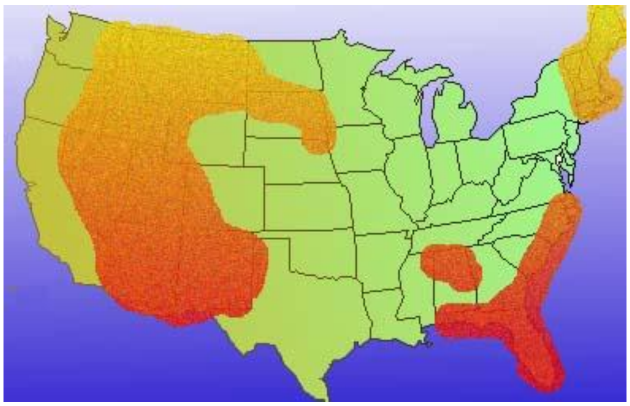
The U.S. Forest Service, Bureau of Land Management, Washington State Department of Natural Resources, and local area fire districts are responsible for the response and suppression of wildland fires in Washington. Washington's Department of Natural Resources is "the state's largest on-call fire department with 1,200 temporary and permanent employees who fight fires on about 12 million acres of private and state-owned forest lands". The Bureau of Land Management (BLM) manages several hundred thousand acres of public lands located mostly in the central Columbian Basin and the Northeast Highlands of Washington near the Canadian border. The U.S Forest Service (USFS) manages 9.3 million acres of public lands located mostly along the spine of the Cascade Mountains, along the Canadian border, and around the Olympic Peninsula. The BLM and USFS have seasonal and permanent employees and equipment to fight wildfires on federal lands.

These agencies, along with tribal entities, U.S. Fish & Wildlife, and the fire chiefs associations for Washington and Oregon, form the Pacific Northwest Wildfire Coordinating Group (PNWCG). This group provides a coordinated interagency approach to wildfire management in Oregon and Washington. The Northwest Interagency Coordination Center (NWCC) serves as the focal point for these agencies resource coordination, logistics support, aviation support, and predictive services for all state and federal agencies involved in wildland fire management and suppression in Washington and Oregon. The NWCC provides daily significant fire potential maps for the region along with daily situation reports, briefings and large fire information summaries for local, county, and state emergency managers to keep updated on the status of these incidents.

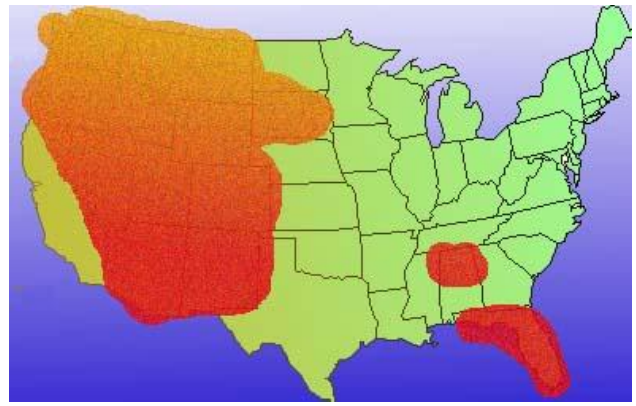
Figure 128 Burnout operations along Highway 12 for Yakima Complex Fire, DNR 2012

Fire Seasons[336]

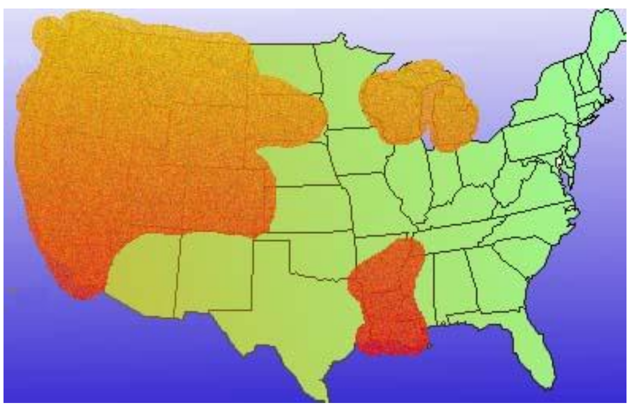
The wildland fire season in Washington State usually begins in early July and typically culminates in late September. The fire season typically is longer in Eastern Washington than in Western Washington because the eastern side is drier and has a larger number of ignition sources, primarily the number of lightning strikes. The western half of the state receives more rainfall and has spring seasons that are wetter and cooler than the east thereby keeping the ignitability of the forest down.



Fire Season – June



Fire Season – July



Fire Season – August

Fire Season – September

Figure 128 Source: Firewise Communities Program / USDA Forest Service

Impact of Wildland Fire on State-Owned or Protected Land[337]

From 2008 through 2012, the cost of wildland fire on state-owned or protected lands is more than $34 million annually in firefighting and damages.

During this time period wildland fires caused about $14 million in damage annually. The bulk of the losses are harvestable timber and timber products valued at more than $6.8 million. Fire also destroys forage, wildlife, watersheds, recreation areas, and real and personal property valued at approximately $7.2 million.

Data on indirect impacts of wildland fire, such as the economic loss caused by reduced revenue and tax receipts from reduced timber and crop sales or leasing of rangeland, is not available.

Previous Occurrences[338, 339, 340, 341, 342, 343]

The State of Washington has received 62 Fire Management Assistance Declarations from the Federal government since 1970. Table 92 below provides information on some of the most significant wildland fires in Washington since 1900, some of which resulted in Fire Management Assistance Declarations. The table provides summary information for fires on lands of all ownership – federal, state, local, private, and Indian tribe.

Table 92 Significant Wildland Fires Since 1900

Year	Fire	Area	Acres Burned	Impacts
1902	Yacolt	Skamania, Clark Counties	238,900	38 deaths.
1910	Great Idaho Fire	Spokane and Pend Oreille Counties	150,000	3 million acres burned, mostly in Idaho and Montana; considered one of the nation's historically significant fires.
1929	Dole Valley Toats Coulee	Skamania, Clark Counties Okanogan County	227,500 80,000	
1951	Great Forks Fire	Clallam County	33,000	Fire threatened Forks leading to evacuation of the town. A sawmill, and a number of homes, cabins and barns destroyed.
1970	Lightning Bust	Chelan, Okanogan Counties	188,000	
1985	Barker Mountain	Okanogan County	60,000	
1987	Hangman Hills	Spokane	1,500	2 deaths; 24 homes destroyed.
1988	Dinkelman	Chelan County	50,000	1 death.
1991	Firestorm 1991	Ferry, Lincoln, Stevens, Pend Oreille, Spokane, and Whitman Counties	35,000	92 fires destroyed 114 homes and 40 buildings, another 250-300 buildings damaged, one death. Fires started by arcing electrical connections, spread over wide area by high winds. Federal Disaster #922. Stafford Act disaster assistance provided: $12.3 million.
1992	Skookum	Klickitat County	51,000	Threatened town of Goldendale
1992	Castlerock Canyon	Wenatchee		24 homes destroyed.
1994	Tyee Creek, Hatchery Creek, Rat Creek, Round Mountain	Chelan County	180,000	2,700 homes threatened and evacuated, 37 homes destroyed.
1996	Cold Creek	Benton, Yakima Counties	57,000	
2000	24 Command	Hanford Site, Benton County	192,000 (160,000 on Hanford Site)	Caused by vehicle accident, spread to Hanford Site; 36 structures lost. Burned across three radioactive waste disposal sites, no radioactive release detected. Fire came within two miles of 177 underground storage tanks filled with lethal radioactive waste.
	Mule Dry	Yakama Indian Reservation and Yakima, Klickitat, and Benton Counties	76,800	1 home destroyed.
2001	Rex Creek Complex / Virginia Lake Complex	Colville Indian Reservation and Chelan, Ferry, Okanogan Counties	130,000	Hundreds of homes threatened, 10 destroyed.

Table 92 Significant Wildland Fires Since 1900

Year	Fire	Area	Acres Burned	Impacts
	Thirtymile	Okanogan	9,300	4 firefighters died.
2002	Deer Point	Chelan County	42,665	5 homes, 4 outbuildings destroyed.
2005	School	Columbia, Garfield counties	52,000	109 homes, 106 outbuildings destroyed; 120 homes, 56 outbuildings threatened. $15 million suppression costs.
2006	Tripod	Okanogan County	175,184 (11,465 on DNR protection)	
	Spur Peak	Okanogan County	14,000	
	Tin Pan	Chelan County	9,252	
	Columbia Complex	Columbia, Walla Walla	109,402	Lost 11 homes and 8 outbuildings. Damaged 800 homes and 31 outbuildings. Threatened 350 outbuildings.
2007	Easy Street	Chelan County	5,209	Fireworks caused. 1 outbuilding lost. 2150 homes threatened
	Horse Heaven Hills	Benton County	28,575	WFS mobilization fire
	Tunk Grade	Okanogan County	15,540	95 homes threatened
	Domke Lake	Okanogan Wenatchee Forest	11,900	
	South Omak Lake Fire	Okanogan County	10,500	
2007	Wautoma	Benton County	67,000	Grass fire on wildlife refuge
	Manila Creek	Colville Reservation, Ferry County	26,805	
2008	Badger Mountain	Chelan and Douglas Counties	15,023	Unknown number of homes threatened
	Spokane Valley	Spokane County	1,008	2400 people evacuated, 1900 notified of evacuation. 200 homes threatened, 40 damaged, 12 homes, 14 outbuildings, and 1 communication site destroyed
	Columbia River Road	Okanogan County	22,115	
	Swanson Lake	Lincoln County	19,090	Destroyed 1 abandoned residence, 2 seasonal cabins, and 15 outbuildings
2009	Dry Creek Complex	Yakima and Benton Counties	48,902	1,000 structures threatened
	Oden Road	Okanogan County	9,607	Destroyed 2 homes and 10 outbuildings
	Discovery	Yakima County	4,120	Burned on National and State forest land
2010	Eureka	Walla Walla County	21,620	

Table 92 Significant Wildland Fires Since 1900				
Year	Fire	Area	Acres Burned	Impacts
	Wenatchee River Complex	Chelan County	2,270	Over 400 homes threatened
	Rainbow Bridge	Chelan County	3,710	Threatened 200 homes in Stehekin
	Swakane	Douglas County	17,115	Threatened homes, structures and utility lines
	Highway 8	Klickitat County	2,019	Threatened 50 homes and 100 structures
2011	Salmon	Okanogan County	1,631	28 homes threatened
	Monastery	Klickitat County	3,626	Destroyed 29 homes and 79 outbuildings
2012	Taylor Bridge	Kittitas County	23,500	Destroyed 61 homes and 211 outbuildings
	Wenatchee Complex	Chelan, Douglas and Kittitas Counties	56,478	17 fires that threatened 260 homes
	Table Mountain	Kittitas County	42,312	Threatened 600 homes, destroyed 3 outbuildings
	Cascade Creek	Skamania and Yakima Counties	20,296	Burned Gifford Pinchot Wilderness Area and threatened portions of Pacific Crest Trail
	Barker Canyon Complex	Douglas County	81,155	Destroyed 3 homes and 9 outbuildings
	Apache Pass	Lincoln County	23,324	Threatened 100 homes, destroyed 4 outbuildings
	Antoine 2	Chelan and Okanogan Counties	6,837	Threatened 50 homes
	St Marys Mission Road	Okanogan County	17,031	Destroyed 2 homes and 8 outbuildings
	Buffalo Lake Road	Okanogan County	11,299	Threatened Coulee Dam and Elmer city
	Yakima Complex	Kittitas and Yakima Counties	2,300	Over 100 fire starts, Hwy 12 closures, threatened 25 homes
	Okanogan Complex	Okanogan County	6,169	4 fires that threatened 75 homes
	Highway 141	Klickitat County	1,644	Threatened 50 homes

Figure 129 Smoke from Powerline 2 Fire, DNR 2012

Figure 130 Antoine 2 Fire along Highway 97, DNR 2012

Major Wildland Fires on State-Owned or Protected Lands, 1992-2012[344, 345, 346]

Table 93, below, provides information on some of the most significant wildland fires on state-owned or protected lands during the latest 16-year period. (Note: List below generally does not include fires referenced above. Acreage burned figures are for state-owned or protected lands only; fires may have burned land under other ownership/protection.)

Table 93 Major Wildland Fires on State Protected Lands, 1992 – 2012

Year	Fire	County/Area	Acres	Impacts
1992	Skookum	Klickitat	2,600	Fire threatened town of Goldendale. Acres for state protected lands only.
1996	Bowie Road	Spokane	3,020	8 homes destroyed.
1997	Red Lake	Stevens	1,151	5 homes destroyed.
1998	Cleveland	Klickitat	18,500	11 homes destroyed, 143 cattle killed. Several cultural and historic sites and state natural area preserve damaged.
1999	Mallot	Okanogan	2,808	
2000	Alderdale	Klickitat	6,000	
	Rocky Hull	Okanogan	9,404	37 homes destroyed.
	Cayuse	Okanogan	5,460	
	Goodnoe	Klickitat	4,455	Destroyed pastureland, 1 barn.
	Buffalo Lake	Colville Indian Reservation	9,300	
	Wood Gulch	Klickitat	2,620	
2001	Libby	Okanogan	3,830	50 structures threatened, none lost.
	Spruce/Dome Complex	Yakima	2,442	
	Brewster Complex	Okanogan	6,154	
	Union Valley	Chelan	4,700	100 structures threatened, 3 destroyed.
	North Coppei	Columbia	4,810	
2002	Deer Mountain	Chelan	2,281	
2004	Mud Lake		4,000	
	Pot Peak-Sisi Ridge	Chelan	47,170	
2005	Dirty Face	Chelan	1,150	$6.7 million suppression costs.
	Second Hud	Okanogan	4,274	$2 million suppression costs.
	West Omak Lake	Okanogan	11,325	$2 million suppression costs.
	Wood Gulch	Klickitat	5,400	$500,000 suppression costs.
2006	Columbia Complex	Columbia, Walla Walla	109,402	Lost 11 homes and 8 outbuildings. Damaged 800 homes and 31 outbuildings. Threatened

Year	Fire	County/Area	Acres	Impacts
Table 93 Major Wildland Fires on State Protected Lands, 1992 – 2012				
				350 outbuildings.
	Tripod Complex	Okanogan	175,184	11,465 acres on DNR protection lands
2007	Easy Street	Chelan	5,209	Caused by Fireworks. 1 outbuilding lots; 2,150 homes threatened.
	Tunk Grade	Okanogan	15,540	95 homes threatened
2009	Oden Road	Okanogan	9,607	Destroyed 2 homes and 10 outbuildings
	Discovery	Yakima	4,120	Burned on National and State forest land
2010	Swakane	Douglas	17,115	Threatened homes, structures and utility lines
	Highway 8	Klickitat	2,019	Threatened 50 homes and 100 structures
2011	Salmon	Okanogan	1,631	28 homes threatened
	Monastery	Klickitat	3,626	Destroyed 29 homes and 79 outbuildings
2012	Taylor Bridge	Kittitas	23,500	Destroyed 61 homes and 211 outbuildings
	Highway 141	Klickitat	1,644	Threatened 50 homes

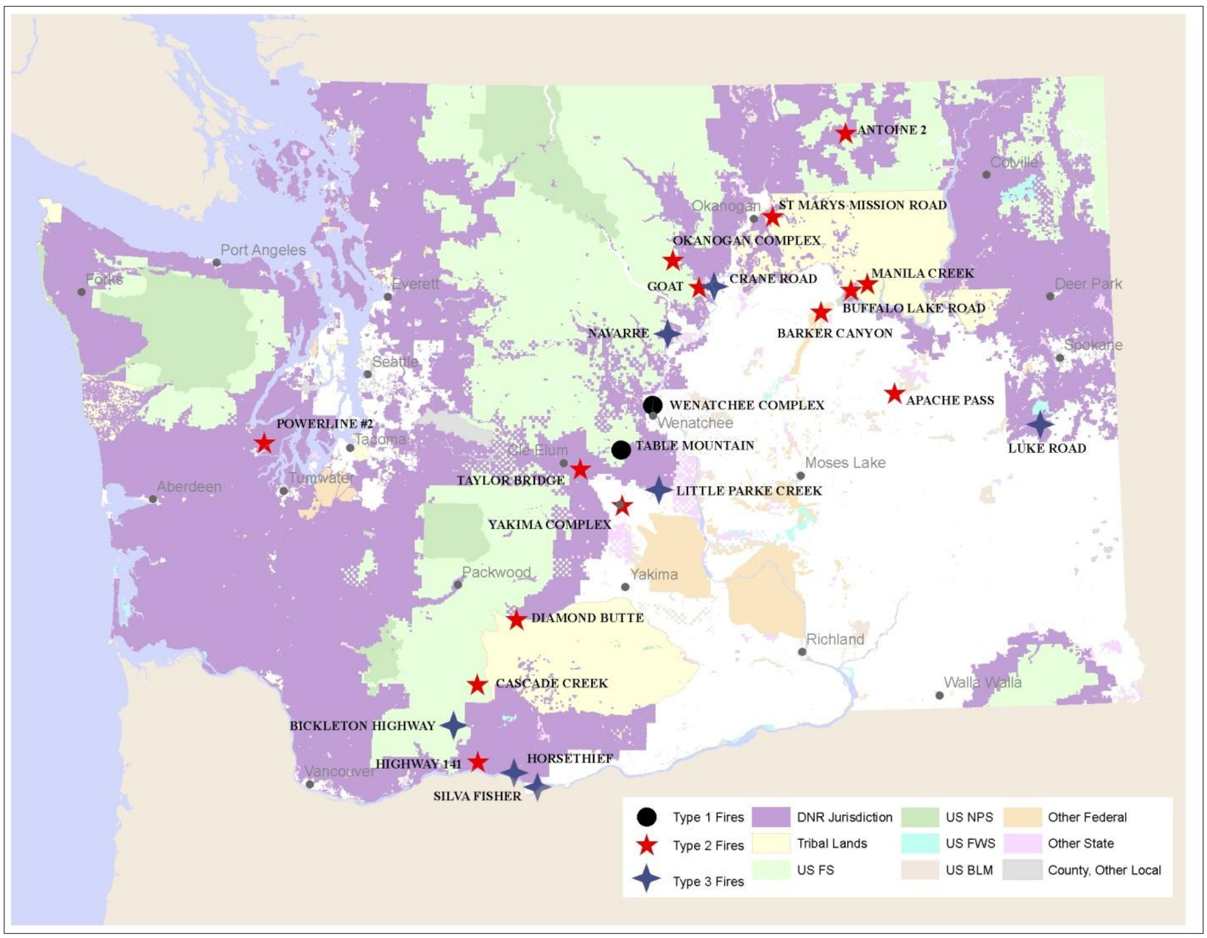


Figure 131 Washington Department of Natural Resources (DNR) 2012

Probability of Future Events[347]

While wildfire has always played a big role in the forests of the western United States, the risk to public safety, private property and the quality of life in Washington has changed. There are more people living, recreating, and working in the woods. Washington State's forests are in jeopardy. Wildfires create public health and water quality problems. Wildfires now increasingly burn with intensities that reduce or eliminate habitat for threatened and endangered species. The direct and indirect consequences of wildfire on the people in the state, and the state's economy and environment are real.

The last comprehensive look at DNR's fire program was completed in 2006. Previously, it was 1986. Today, there is an additional 1.6 million people in the State, a 40% increase since 1986. There are now more homes in the woods, homes often without any fire protection. Climate change and other factors have substantially reduced forest health. The results are increased risks to public safety and firefighter safety, compounded by the increased costs of fire suppression, and accelerated losses of landowner timber value.

Table 94 provides summary information, by county, for the number of fires and number of acres burned for the period 2003-2012. The data was provided by Washington Department of Natural Resources.

Table 94 County	2003 fires	2003 acres	2004 fires	2004 acres	2005 fires	2005 acres	2006 fires	2006 acres	2007 fires	2007 acres	2008 fires	2008 acres	2009 fires	2009 acres	2010 fires	2010 acres	2011 fires	2011 acres	2012 fires	2012 acres	County total fires	County total acres burned
Adams County	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	1
Asotin County	0	0	3	30.2	3	150.5	3	2.5	6	21019.3	4	0.7	5	0.56	2	0.1	0	0	6	2558.6	32	23762.41
Benton County	1	0.3	0	0.0	2	0.0	0	0. 0	3	101575	0	0	0	0	0	0	0	0			6	101575.3
Chelan County	25	21.2	51	184.3	47	33.4	38	112.2	43	5086.6	36	250.3	50	3034.3	50	19502.5	27	353.59	45	56457.8	412	85036.11
Clallam County	21	43.8	28	24.0	29	3.8	32	19.7	11	12.4	18	5.3	33	16.3	19	4.67	23	6.11	29	10.55	243	146.6
Clark County	32	7.6	27	8.1	28	12.1	21	16.6	33	8.9	25	27.8	24	68.21	13	118.18	19	3.7	25	143.6	247	414.67
Columbia County	5	3.5	1	0.1	3	25010.0	11	821.6	12	10.3	4	0.8	6	0.13	4	200.51	5	0.54	4	0.95	55	26048.33
Cowlitz County	62	25.2	35	40.2	26	58.9	46	134.6	19	12.1	29	59.1	59	98.93	17	111.49	55	12.29	49	20.4	397	573.14
Douglas County	1	0	4	5.0	0	0.0	3	3.0	1	1.0	4	10204	1	15	4	3086	3	600	12	94996.3	33	108910.3
Ferry County	15	32.6	60	23.2	24	10.0	32	549.8	26	41.1	50	1854.7	58	49.97	26	704.28	15	6.19	25	541.39	331	3813.26
Garfield County	0	0	0	0.0	0	0.0	1	0.1	2	0.0	8	2601.6	0	0	1	0.5	4	1.1	1	0.25	17	2603.55
Grant County	0	0	0	0.0	0	0.0	1	5000.0	2	760.0	0	0	2	0	1	0	1	0	1	470	8	6230
Grays Harbor County	24	66.2	32	20.5	29	21.5	49	81.1	30	16.8	15	14.2	18	12.2	15	7.46	15	6.45	20	44.55	247	290.95
Island County	13	24.2	5	2.1	2	1.0	6	0.5	4	0.6	2	0.4	8	1.85	2	1.1	0	0	6	0.75	48	32.41
Jefferson County	15	20	16	5.3	18	26.0	37	11.6	23	3.2	10	1.6	28	449.8	10	8.52	9	24	12	5.56	178	555.61

Table 94 County	2003 fires	2003 acres	2004 fires	2004 acres	2005 fires	2005 acres	2006 fires	2006 acres	2007 fires	2007 acres	2008 fires	2008 acres	2009 fires	2009 acres	2010 fires	2010 acres	2011 fires	2011 acres	2012 fires	2012 acres	County total fires	County total acres burned
King County	10	17.3	20	2.8	42	2.3	10	0.2	10	0.2	25	10.7	43	25.33	7	1.3	6	1.14	10	7.28	183	68.6
Kitsap County	10	19.6	6	1.0	4	1.5	3	5.2	3	5.2	1	0.01	3	1.31	2	0	0	0	3	2.65	35	36.32
Kittitas County	30	197.3	86	1611.2	44	16.3	38	559.5	38	559.5	53	739.5	41	138.61	29	64.64	38	778.39	61	67204.9	458	71869.84
Klickitat County	54	76.3	149	320.0	79	113.3	54	1237.7	54	1237.6	63	415.7	60	1337.26	40	3276.64	36	3736.48	43	3119.35	632	14870.22
Lewis County	44	33.3	48	85.1	39	80.2	16	4.2	16	4.2	19	37.7	29	15	11	7.46	15	7.22	34	41.01	271	315.42
Lincoln County	6	18.5	9	340.1	8	1005.2	11	1669.4	11	1669.4	6	19140.3	11	35.12	13	408.56	8	34.52	23	24559.5	106	48880.66
Mason County	60	48.4	65	33.5	66	133.1	33	61.0	33	61.0	43	26.8	37	43.2	19	91.31	29	57.82	47	263.94	432	820.14
Okanogan County	57	1984.3	216	5284.0	88	11785.0	103	16591	95	16948.9	168	33272.8	245	13891.8	112	636.37	78	3461.29	141	43781.4	1303	147636.26
Pacific County	22	10.6	9	36.8	16	43.2	26	12.3	9	1.6	9	19.8	14	11.76	7	4.25	5	1.08	12	12.1	129	153.44
Pend Oreille County	33	13.7	30	3.8	24	10.9	66	18.5	40	15.2	41	26.9	52	19.08	35	60.67	29	14.39	28	26.18	378	209.34
Pierce County	21	34.1	35	43.5	16	24.3	32	448.9	18	6.2	19	45.7	37	25.63	16	2.7	24	6.9	29	42.83	247	680.74
San Juan County	14	5.2	7	2.4	5	0.7	4	5.8	1	0.1	7	2.7	7	4.15	11	7.97	3	1.7	9	2.75	68	33.28
Skagit County	24	55	18	2.0	12	2.2	19	54.3	19	1.0	15	5.3	35	44.85	7	0.76	16	13.22	18	26.34	183	204.97
Skamania County	19	13.7	19	5.4	24	13.3	26	5.7	15	133.5	12	2.7	17	101.07	13	2.22	15	3.04	19	3.47	179	284.05
Snohomish County	29	59.1	24	47.5	9	2.7	21	22.8	17	5.4	13	7.5	27	213.7	12	9.04	15	3.63	25	7.24	192	378.64
Spokane	13	138	10	331.	11	125	14	444	16	545.	10	111	14	134.	72	911.	11	235.	15	334.	125	6695.

Table 94 County	2003 fires	2003 acres	2004 fires	2004 acres	2005 fires	2005 acres	2006 fires	2006 acres	2007 fires	2007 acres	2008 fires	2008 acres	2009 fires	2009 acres	2010 fires	2010 acres	2011 fires	2011 acres	2012 fires	2012 acres	County total fires	County total acres burned
County	5	5.5	6	4	8	7.5	9	.7	2	5	8	5.2	1	41		18	2	96	0	32	3	58
Stevens County	145	3991.2	167	117.7	100	975.5	151	966.7	154	971.7	189	1264.5	160	366.91	123	2071.25	75	130.05	113	353.92	1377	11209.43
Thurston County	68	33.8	66	101.3	39	96.0	95	58.2	30	12.9	34	18.60	52	47.53	19	3.77	20	11.82	0	0	423	383.93
Wahkiakum County	0	0	3	0.2	5	30.5	5	1.1	0	0.0	4	0.95	2	3.4	3	7.26	0	0	3	0.3	25	43.7
Walla Walla County	1	0.1	0	0.0	3	250.1	7	44636	5	65.0	3	2.1	3	1.02	0	0	1	0	1	0.1	24	44954.54
Whatcom County	9	7.3	21	107.3	13	22.9	15	1.6	13	1.9	13	16.3	23	310.45	10	1.12	10	1.88	17	1.97	144	472.58
WHITMAN	0	0	0	0.0	0	0.00	0	0.00	0	0.0	1	2172	0	0			1	310	0	0	2	2482
Yakima County	18	3983.3	39	4014.6	18	498.5	28	149.9	23	439.2	31	8285.66	38	5656.66	25	266.17	23	426.32	35	6921.5	278	30641.73
TOTALS	1023	12232.2	1405	12834.5	983	41692.2	1192	73707	981	151232	904	66645.4	1369	26175.5	751	31580.9	735	10250.8	1056	301964		

The DNR worked collaboratively with an external Advisory Committee, looking at today and where we wanted the state's fire program to be in 2020. The Strategic Plan started with a focus on wildfire suppression. Quickly, it became clear that a broader view was necessary. The focus changed to wildland fire protection, the interaction between forest health, wildfire readiness, wildfire prevention, and wildfire suppression. The Pathway to 2020 Phase II is the latest rendition supporting the DNR Strategic Plan for Wildfire Protection.

DNR is responsible for preventing and fighting wildfires on 12.7 million acres of private, state, and tribal-owned forestlands. DNR is the state's largest on-call fire department, with over 1,000 employees trained and available to be dispatched to fires as needed. During fire season, this includes over 700 DNR employees who have other permanent jobs with the agency and about 400 seasonal employees hired for firefighting duties. Additionally, Department of Corrections' adult offenders and Department of Social and Health Services-Juvenile Rehabilitation Administration juvenile offenders participate in the DNR correctional camps program. DNR also participates in Washington's coordinated interagency approach to firefighting.

Human and lightning caused wildfires will continue to occur in Washington State. DNR reports that approximately 76% of all DNR jurisdiction wildfires from 2008-2012 were caused by humans. Based on figures from 1993 through 2012, about 850 fires have occurred annually on state protected lands (Chart 133), burning over 22,000 acres each year (Chart 134), Frequency of Occurrence [348]

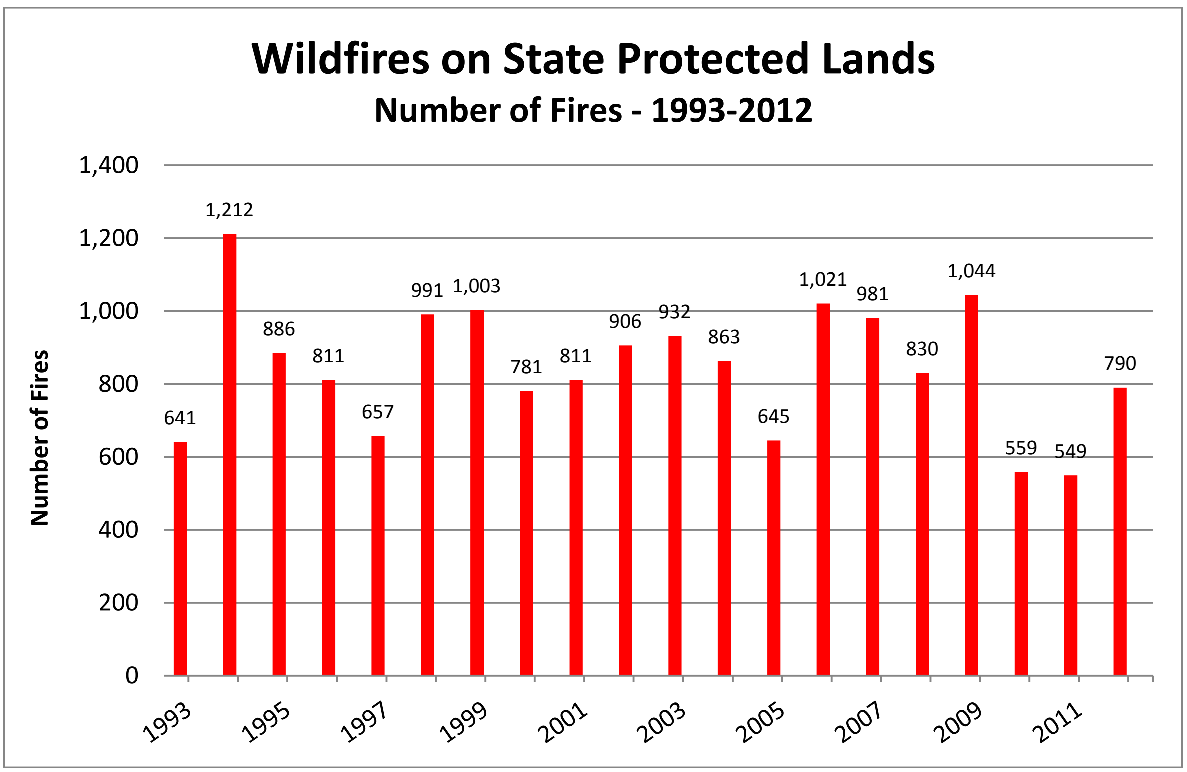


Figure 133 Washington Department of Natural Resources (DNR) 2012

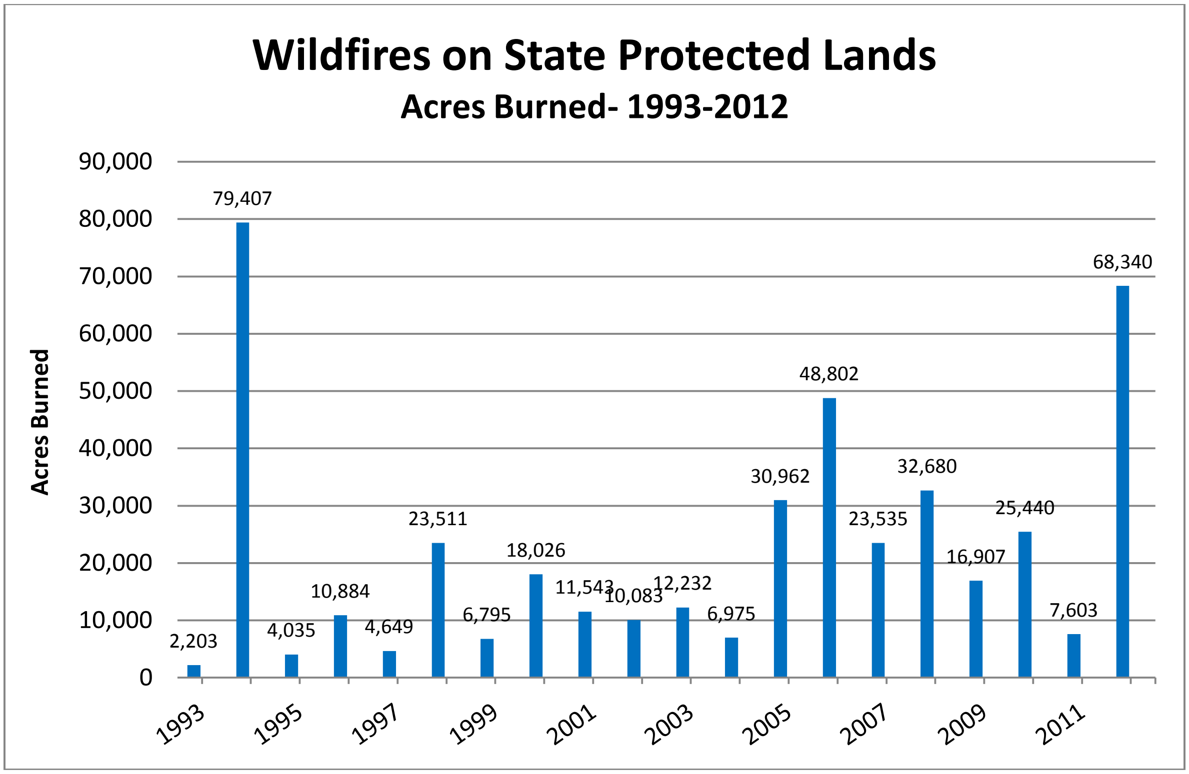


Figure 134 Washington Department of Natural Resources (DNR) 2012

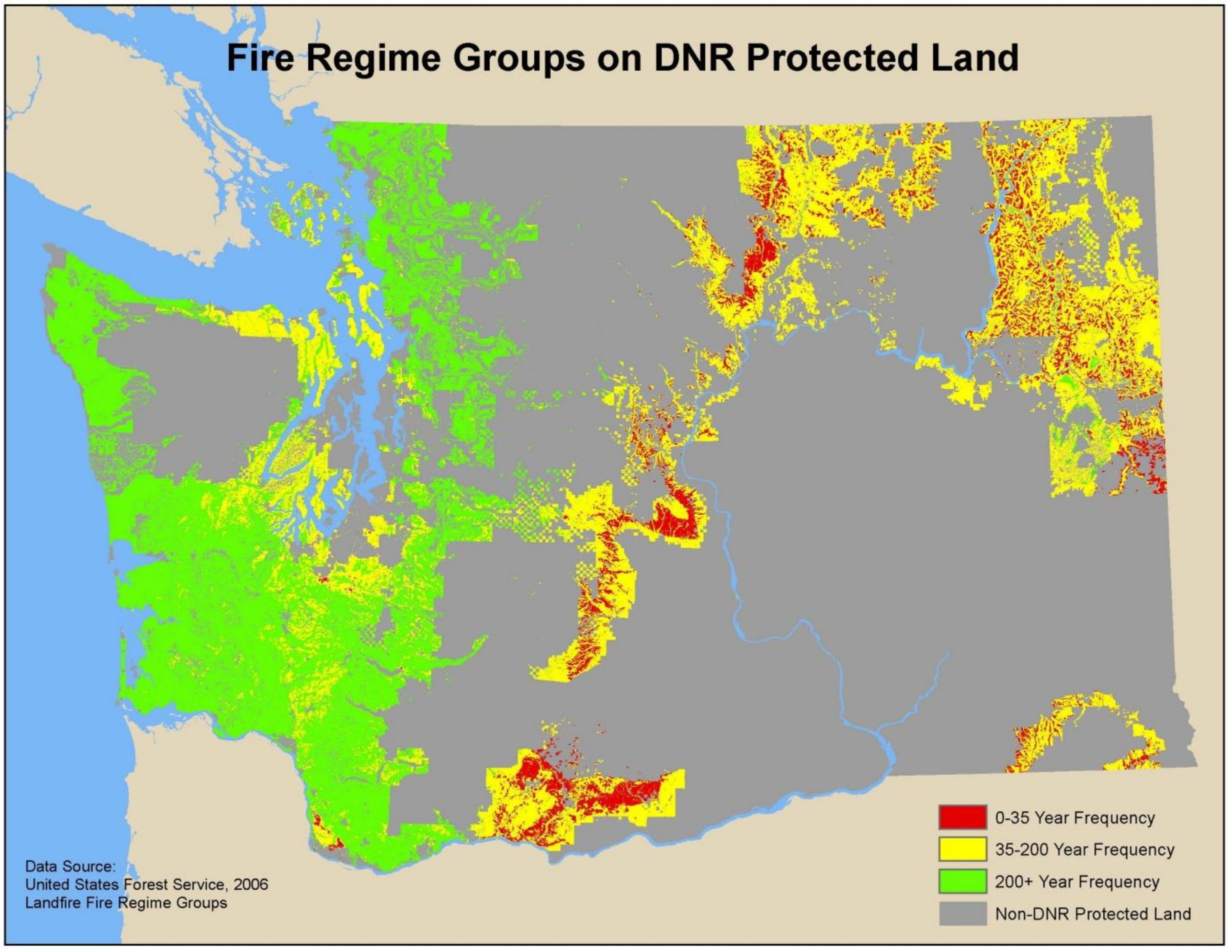


Figure 135 Washington Department of Natural Resources, (DNR) 2012

***Mean Fire Return Interval*[349]**

The Mean Fire Return Interval map (below) quantifies the average period between fires under the presumed historical fire regime. This frequency is derived from vegetation and disturbance dynamics simulations using LANDSUM (Keane and others 2002, Hann and others 2004). This layer is intended to represent one component of the presumed historical fire regimes within landscapes based on interactions between vegetation dynamics, fire spread, fire effects, and spatial context.

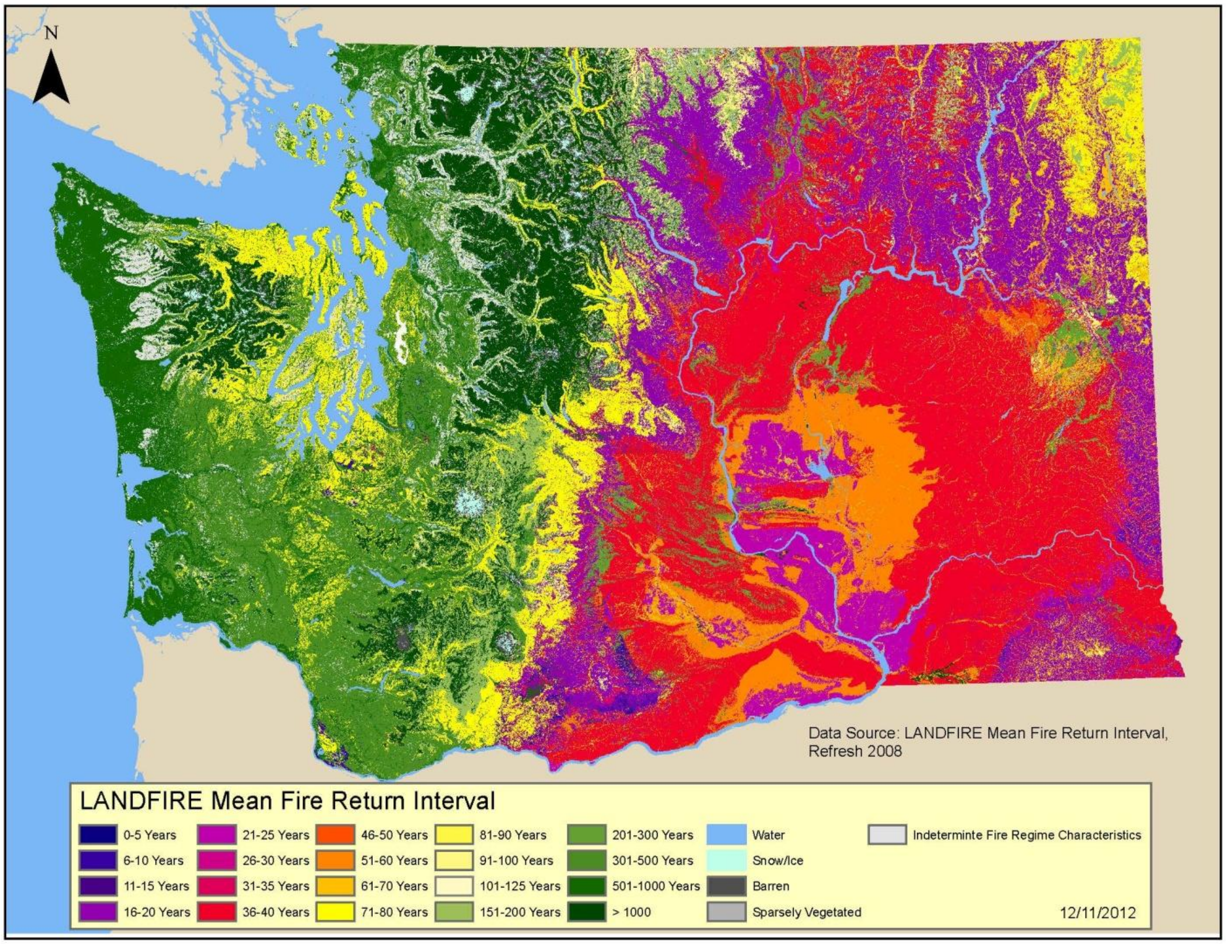


Figure 136 Washington Department of Natural Resources, (DNR) 2012

Jurisdictions Most Threatened and Vulnerable to Wildland Fire[350,351]

The wildland–urban interface (WUI) is commonly described as the zone where structures and other human development meet and intermingle with undeveloped wildland or vegetative fuels. This WUI zone poses tremendous risks to life, property, and infrastructure in associated communities and is one of the most dangerous and complicated situations firefighters face.

The Washington Department of Natural Resources and its federal and local partners determined the listed communities were at high risk after evaluating them for fire behavior potential, fire protection capability, and risk to social, cultural and community resources. Risk factors included area fire history, type and density of vegetative fuels, extreme weather conditions, topography, number and density of structures and their distance from fuels, location of municipal watershed, and likely loss of housing or business. The evaluation used the criteria in the wildfire hazard severity analysis of the NFPA 299 Standard for Protection of Life and Property from Wildfire. Consequently, Washington's State Forester (DNR) designated 221 Wildfire-Urban Interface Communities are high risk to wildfire.

Table 95 Urban Interface Communities at High Risk to Wildfire (DNR) 2012

COMMUNITY_NAME	HAZARD_RATING	COMMUNITY_NAME	HAZARD_RATING	COMMUNITY_NAME	HAZARD_RATING
12 Mile/LPO	High	Castle Rock	High	Deadman	High
7 Mile	Extreme	Cedar Creek	High	Deep Lake	Extreme
Aeneas Valley	High	Cedonia	Extreme	Deer Lake	High
Ahtanum	Extreme	Centralia Alpha	High	Dennison Chattar	High
Alta Lake	High	Chain Lakes	Extreme	Devil Mtn.	High
Amboy	High	Chewelah Golf Co	High	Diamond Lake East	High
Asotin Creek	High	Chiliwist	High	Ellensburg	Moderate
Aspen Meadows	High	Chuckanut Mtn.	High	Elk Heights	High
Bakers Pond	Moderate	Chumstick	Extreme	Ellensburg Pass	Extreme
Beacon Hill	Extreme	Cinebar	High	Enterprise	High
Bead Lake	Moderate	Clayton	High	Entiat	High
Belle Vista	High	Cle Elem	Extreme	Enumclaw	High
Ben Howard	High	Cloverland	Extreme	Fertile Valley	High
Big Lake	High	Colockum	Extreme	Fidalgo	High
Blewett	High	Conconully	Moderate	Field Spring	Extreme
Blue Slide	High	Concrete	Extreme	Finley-Dry Gulch	High
Brender Canyon	Extreme	Cooper Point	High	Flowery Trail	High
Burnt Valley	High	Cowiche	Extreme	Flowery Trails	Extreme
BZCorners	High	Coyote Trail	High	Foothills	High
Cabin Creek	Extreme	Crawfish Lake	Extreme	Ford	Extreme
Camano	High	Crumbacher	Moderate	Four Mounds	High
Capitol Forest	High	Curlew	High	Furport	High
Carlton	High	Darrington/Sauk	Extreme	Geiger	Extreme
Carnation	High				

COMMUNITY_NAME	HAZARD_RATING
Glacier	High
Glenoma	Extreme
Glenwood	Extreme
Grande Ronde	Extreme
Green Canyon	Extreme
Greenwater	High
Grouse Flats	Extreme
Guemis	Extreme
Haward	Extreme
Herron Creek	High
High Prairie	Extreme
Highway 410	High
Hockinson	High
Icicle Creek	Extreme
Index	High
Jim Creek	High
Johnson Point	Extreme
Jump Off	High
Kalama	High
Kalispell Reservation	Moderate
Kelly Hill	High
Kelso	High
Kendall	High
Kettle Falls	High
Kitsap North	Moderate
Kitsap South	Moderate
Klickitat East	High
Klickitat Heights	Extreme
Klickitat Valley	High
Lake Chelan North	High
Lake Chelan South 1	High
Lake Chelan South 2	High
Lake Kachness	High
Lake Lawrence	Extreme
Lake Wenatchee	High
Liberty	Extreme

COMMUNITY_NAME	HAZARD_RATING
Liberty Lake	Extreme
Limebelt	Extreme
Longview	High
Lookout Mtn	High
Loomis	Moderate
Loon Lake	High
Lopez	Low
Lower Lake Cle E	Extreme
Lower Lake Keech	Extreme
Lower Valley Nor	High
Lower Valley River	High
Lower Valley South	High
Lower Wenas	Extreme
Lummi	High
Makah	Low
Malloy Prairie	Extreme
Malo East	High
Maloney Mountain	High
Manastash	Extreme
Marblemount	Extreme
Marshall	Extreme
Martin/Mossy	Extreme
Mason	High
Mazama	High
McCoy Flats	Extreme
Midway	High
Mill Creek	High
Mission Creek	Extreme
Montesano	High
Mount Hull	High
Moxee	High
Mt. Loop	Extreme
Mtn Home Rd	Extreme
Mullen Hill	High
National	Moderate
Navarre	High

COMMUNITY_NAME	HAZARD_RATING
Coulee	
Newman Lake	High
Nine Mile	Extreme
Nooksack	Extreme
North Bend	High
NW Goldendale	High
Onion Creek	High
Orcas	Moderate
Orient	High
Oso/Cavanaugh	Extreme
Outer Islands	Low
Painted Hills	High
Park Road	High
Peoh Point	Extreme
Peshastin Creek	Extreme
Pierre Lake	High
Plain	High
Pleasant Prairie	Extreme
Ponderosa	Extreme
Pontiac Ridge	High
Porter	High
Reecer	Extreme
Rendezvous	Moderate
Republic	High
Ridge at Hangman	High
Rimrock	Extreme
Robinette	High
Rochester	Extreme
Rockport	Extreme
Rocky Gorge	High
Roy McKenna	Moderate
Salmon LaSac	Extreme
Samish	High
San Juan	Extreme
Sand Creek	High
Shaw	Low
Sherman	Extreme

COMMUNITY_NAME	HAZARD_RATING
Creek	
Skamania	High
Skykomish	High
Snoqualmie	High
Snowblaze	Low
Snowden	Extreme
South Skagit	High
Springdale	Extreme
Squilchuck	High
Steamboat Island	High
Stemilt	High
Stensgar Creek	High
Stevenson	High
Suncrest	High
Teanaway	Extreme
Teanaway2	High

COMMUNITY_NAME	HAZARD_RATING
Tenino	High
Terrace Heights	High
Tiger	High
Trout Creek	High
Trout Lake	High
Tum Tum	High
Twin Creeks	Extreme
Union Valley	High
Upper Nason Creek	Extreme
Upper Wenas	Extreme
Waitsburg	High
Waitts Lake	High
Washougal	High
Washougal River	High
West Grays	High
West Lewis	Extreme

COMMUNITY_NAME	HAZARD_RATING
West Wenatchee	High
Whatcom	Extreme
Whidbey	Moderate
White River	Extreme
White Salmon	High
White Salmon 1	High
White Swan	High
Winlock	High
Winthrop	High
Woodland	High
Yacolt	High
Yakima Canyon	High

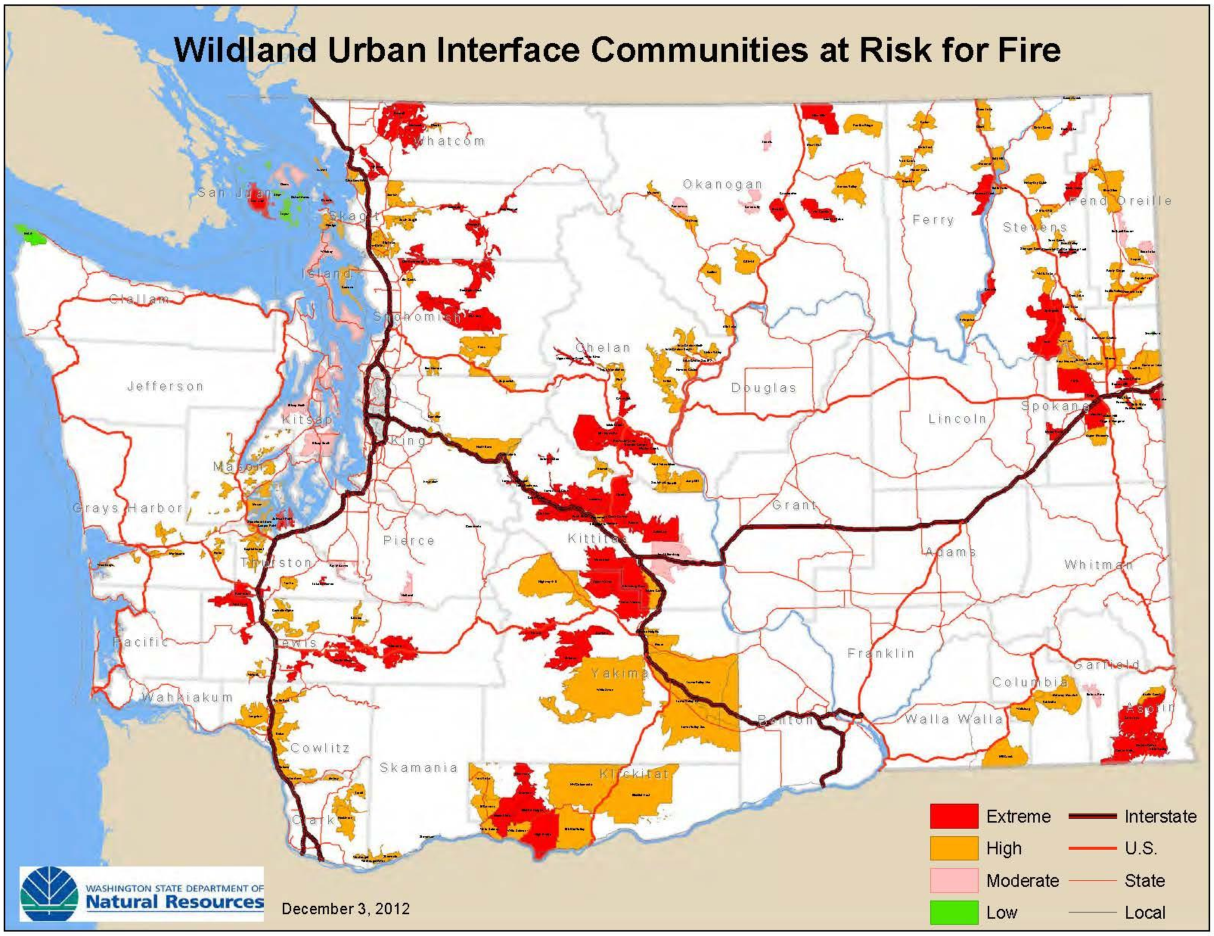


Figure 137 WUI Communities by Zip Code. Department of Natural Resources, 2004

These communities represent over 2/3 of Washington State's thirty nine counties.

Table 96 Counties with Communities at High Risk to Wildfire

Asotin	Chelan	Clallam	Clark	Columbia	Cowlitz	Ferry
Garfield	Island	King	Kitsap	Kittitas	Klickitat	Lewis
Mason	Okanogan	Pend Oreille	Pierce	San Juan	Skagit	Skamania
Snohomish	Spokane	Stevens	Thurston	Walla Walla	Whatcom	Yakima

With the help and guidance of DNR fire prevention staff, 95 Washington communities have earned recognition as a Firewise Community for their wildfire prevention work. Washington State has the second-most Firewise Communities in the nation. The Firewise program encourages local solutions by homeowners, community leaders, planners, developers, firefighters, and others to protect people and property from the risk of wildfire by creating defensible spaces around structures and by minimizing fire ignitable building materials.

Forty-nine communities have mitigation plans or Community Wildfire Protection Plans are part of the fire prevention strategies for Washington's wildland urban interface communities. CWPP are community driven plans for prioritized fuel reduction and treatment of structural ignitability.

While the majority of wildfires in Washington are caused by humans, lightning caused fires burn the most acres.[352] From 2008-2012, DNR reports that approximately 76% of all DNR jurisdiction wildfires were caused by humans.

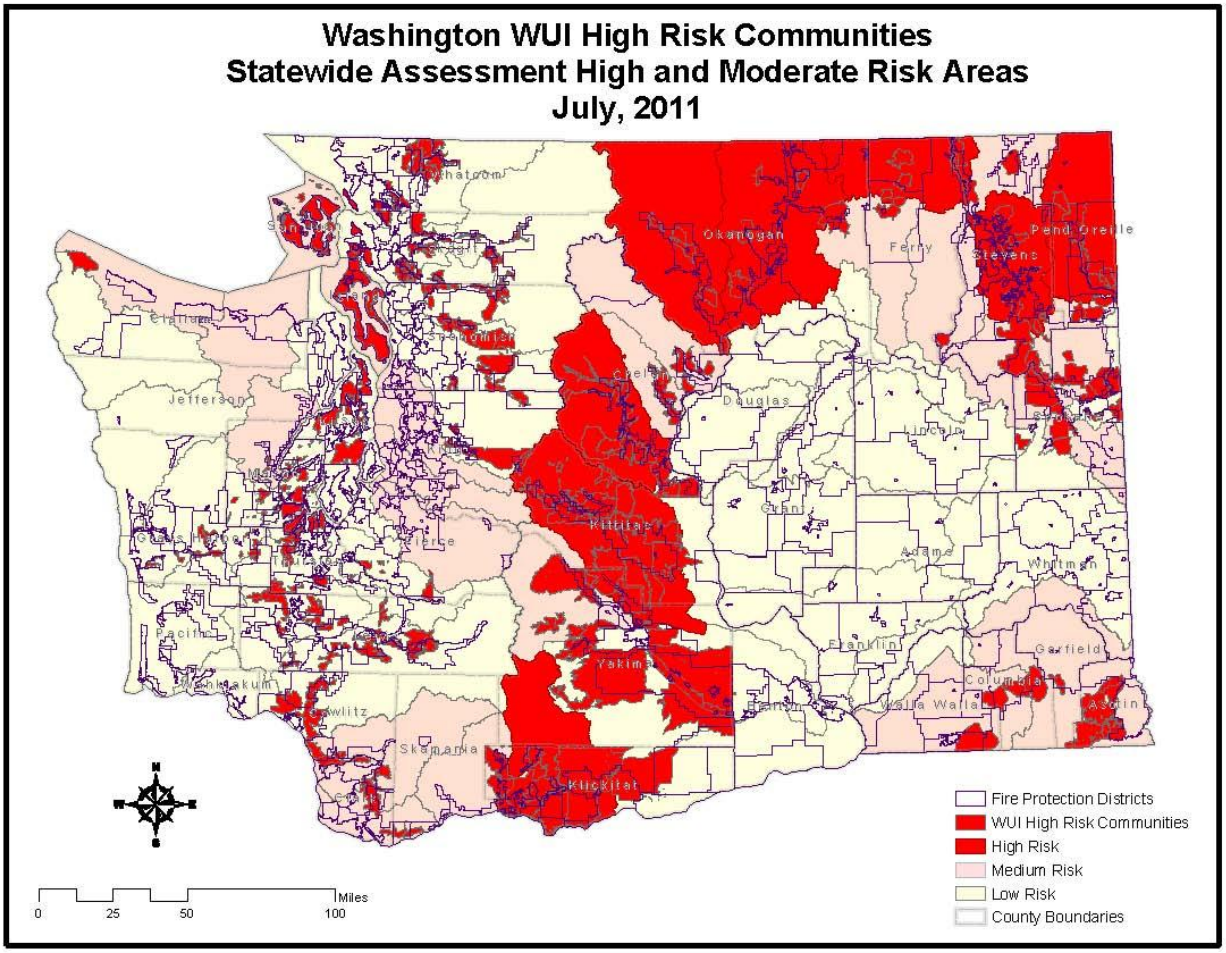


Figure 138 Washington Department of Natural Resources 2011

Potential Climate Change Impacts[353],[354]

According to a 2005 Governor's report prepared by the Climate Impacts Group titled *Uncertain Future: Climate Change and its Effects on Puget Sound*, "from paleoclimatological evidence, we know that over the history of the earth high levels of greenhouse gas concentrations have correlated with, and to a large extent caused, significant warming to occur, with impacts generated on a global scale." While the report also indicates that the "ultimate impact of climate change on any individual species or ecosystem cannot be predicted with precision," there is no doubt that Washington's climate has demonstrated change.

In July 2007, the Climate Impacts Group launched an unprecedented assessment of climate change impacts on Washington State. *The Washington Climate Change Impacts Assessment* (WACCIA) involved developing updated climate change scenarios for Washington State and using these scenarios to assess the impacts of climate change on the following sectors: agriculture, coasts, energy, forests, human health, hydrology and water resources, salmon, and urban stormwater infrastructure. The assessment was funded by the Washington State Legislature through House Bill 1303.

In 2009, the Washington State Legislature approved the *State Agency Climate Leadership Act* Senate Bill 5560. The Act committed state agencies to lead by example in reducing their greenhouse gas (GHG) emissions to: 15 percent below 2005 levels by 2020; 36 percent below 2005 by 2035; and 57.5 percent below 2005 levels (or 70 percent below the expected state government emissions that year, whichever amount is greater.). The Act, codified in RCW 70.235.050-070, directed agencies to annually measure their greenhouse gas emissions, estimate future emissions, track actions taken to reduce emissions, and develop a strategy to meet the reduction targets. Starting in 2012 and every two years thereafter, each state agency is required to report to Washington State Department of Ecology the actions taken to meet the emission reduction targets under the strategy for the preceding biennium.

Recognizing Washington's vulnerability to climate impacts, the Legislature and Governor Chris Gregoire directed state agencies in 2009 to develop an integrated climate change response strategy to help state, tribal, and local governments, public and private organizations, businesses, and individuals prepare. The state Departments of Agriculture, Commerce, Ecology, Fish and Wildlife, Health, Natural Resources and Transportation worked with a broad range of interested parties to develop recommendations that form the basis for a report by the Department of Ecology: *Preparing for a Changing Climate: Washington State's Integrated Climate Change Response Strategy*.

Fire is an important process for recycling dead biomass in the arid west, where natural decomposition rates are extremely slow. However, the National Forest Service Health Forests policy to clean out dead and dying trees in the west to reduce the risk of wildfires blames increasing wildfire activity in the western United States solely on increasing stand density and the buildup of dead fuel as a result of fire exclusion policies; it does not acknowledge any role of changing climate in recent wildfire trends. Many articles and scientific studies suggest wildfires have increased and will continue to increase in number and severity due to the effects of climate change. "Since 1986, longer summers have resulted in a fourfold increase of major wildfires and a six fold increase in the area of forest burned, compared to the period from 1970 to 1986". It has also been noted that the "length of the active wildfire season (when fires are actually burning) in the western United States has increased by 78 days, and that the average burn duration of large fires has increased from 7.5 to 37.1 days".

Four critical factors have been attributed to the increase seen in wildfire activity: earlier snowmelt, higher summer temperatures, longer fire season, and an expanded vulnerable area of high-elevation forests. These factors have all been linked to the increase in overall summer temperatures that can be attributed to the effects of climate change.

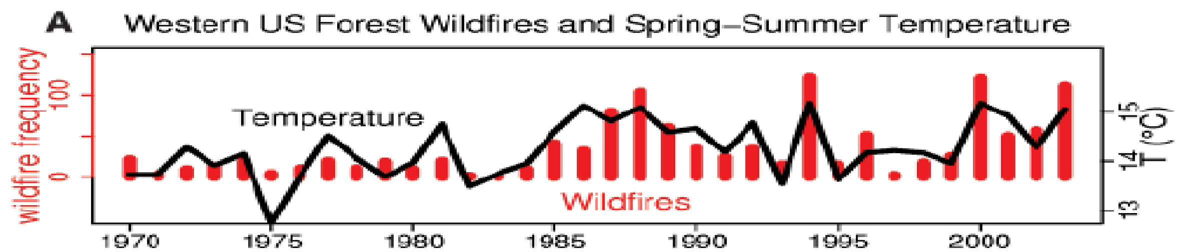


Figure 139 Wildfire Frequency in the Western U.S. and Spring-Summer Temperatures

Some probable effects from climate change include the following:

- Higher forest fire frequency and intensity likely, especially in eastern WA.
- Forests east of the Cascade crest will be most susceptible to larger fires.
- Mountain pine beetle poses a significant threat to Washington's pine forests.
- Tree species composition will change as species respond uniquely to a changing climate.
- Productivity of Douglas-fir forests is likely to decrease statewide.

Healthy Forests

In 2007, the legislature amended state law governing forest health (RCW 76.06). Washington State Department of Natural Resources (DNR) was designated as the agency responsible for implementing a comprehensive program to improve forest health statewide. DNR currently provides insect and disease technical information and education to forest landowners. DNR also monitors forest health to record the extent of insect and disease damage, and gain advanced warning of outbreaks by certain pests.

As forest health problems spread across numerous land ownerships and cause a significant increase in dead trees, fire danger increases significantly. RCW 76.06 authorizes the Commissioner of Public Lands to appoint a technical advisory committee to evaluate the forest health threats and recommend potential remedial actions. This committee is comprised of forest management practitioners and scientific experts. The Commissioner, considering the recommendations of the technical committee and other factors such as local input received at public meetings, may issue a "forest health hazard warning" to publicize the situation and stimulate a coordinated response.

If forest conditions continue to deteriorate, the technical committee can recommend that the Commissioner issue a "forest health hazard order." This would identify the forest health threat in a specific area and require landowners to take remedial action within designated timeframes. Failure to act means landowners could face potential liability for firefighting costs if a wildfire should occur in untreated forests there, unless the problem originated on public lands. The law provides a formal appeal and mitigation process for affected landowners.

In 2012, a Forest Health Hazard Warning was issued for portions of Okanogan, Ferry, Klickitat, and Yakima counties. Landowners in the affected area received a letter notifying them of the warning. DNR held landowner workshops in the affected counties. If requested, Stewardship foresters provided site visits with recommendations.

Figure 140 Retardant drop on Highway 141 Fire, 2012

Table 97 NW Area Fires & Acres by Agency (Federal & State) 1988-2011 Source: Agency-Provided Statistics

Year	BIA Fires	BIA Acres	BLM Fires	BLM Acres	FWS Fires	FWS Acres	NPS Fires	NPS Acres	USFS Fires	USFS Acres	ORODF Fires	ORODF Acres	WADNR Fires	WADNR Acres
1988	207	20,604	317	14,835	9	131	0	02	1,192	133,841	1096	24,868	1,072	11,698
1989	319	4,026	324	38,650	17	1,626	51	116	1,643	85,476	1,115	12,966	1,334	22,252
1990	310	2,113	344	141,797	17	3,719	86	556	2,221	100,368	1,147	11,518	1,142	10,792
1991	339	6,326	333	22,533	17	1,125	41	25	2,130	16,107	1,192	8,148	1,174	7,867
1992	422	25,028	583	73,984	28	2,243	103	1,927	2,315	48,361	1,662	23,482	1,084	41,371
1993	218	1,976	234	9,802	21	2,688	54	212	1,000	3,409	841	2,858	641	2,203
1994	422	50,796	377	329,917	22	389	133	4,896	2,373	281,375	1,445	27,617	1,212	78,291
1995	263	674	307	46,165	39	3,771	103	348	1,176	9,105	1,020	4,979	886	5,227
1996	230	14,1750	436	324,652	28	1,421	55	83	1,612	256,274	1,076	25,529	811	7,075
1997	226	870	327	33,213	29	2,019	92	345	1,159	4,483	815	1,657	657	7,639
1998	316	25,860	267	104,519	7	137	36	18	1,753	13,742	969	2,681	991	23,511
1999	425	22,609	366	39,451	27	45,130	63	299	1,605	9,617	1,182	9,536	1,003	5,890
2000	255	62,276	219	150,245	66	81,125	19	7	1,005	154,531	920	13,248	780	20,139
2001	271	98,139	463	320,400	29	7,339	58	751	1,758	124,105	1,289	51,109	814	22,313
2002	270	14,859	380	181,495	39	2,573	64	458	1,563	772,936	1,175	99,167	892	10,083
2003	252	19,898	275	17,084	39	1,293	78	5,287	1,447	263,970	1,174	8,619	932	10,450
2004	397	25,630	295	1,779	54	1,039	75	654	1,427	66,333	921	5,940	862	14,237
2005	241	28,56	205	36,659	33	11,400	25	129	882	118,20	837	11,605	645	3,579

Table 97 NW Area Fires & Acres by Agency (Federal & State) 1988-2011 Source: Agency-Provided Statistics

Year	BIA Fires	BIA Acres	BLM Fires	BLM Acres	FWS Fires	FWS Acres	NPS Fires	NPS Acres	USFS Fires	USFS Acres	ORODF Fires	ORODF Acres	WADNR Fires	WADNR Acres
		9								7				
2006	348	9,717	368	308,784	46	4,546	37	7,892	1,730	373,027	1,103	7,693	1,021	48,803
2007	349	56,649	288	152,559	93	81,908	41	7	1,191	444,667	1,092	38,682	981	23,835
2008	364	34,102	212	36,369	45	6,139	47	425	1,597	60,017	1,088	7,581	830	32,680
2009	408	9,913	259	10,569	23	793	67	118	1,532	66,864	983	6,407	1,044	16,906
2010	176	3,4794	230	19,719	19	6,933	31	5,148	1,192	41,884	693	6,122	1,203	13,381
2011	245	11,1743	286	148,169	10	90	47	1,216	964	26,910	701	2,599	541	7,552
10yr Avg	308	33,227	298	108,542	42	12,396	52	2,087	1432	233,201	1,036	24,292	922	19,627

At-Risk State Agency Facilities

State Agency facilities identified as being at-risk to wildland fire were determined using geo-spacial software to match their location to the wildland fire-urban interface hazard zone. The results are captured in the table below.

Table 98 STATE AGENCY STRUCTURES AT RISK	**VULNERABILITY ASSESSMENT**	
Number and Function of Buildings	Approx. Square Footage of Facilities	Approx. Value of Owned / Leased Structures and Building Contents
<u>Total at-risk buildings</u>: 1,687 state facilities were identified as being in the wildland fire-urban interface hazard zone potentially at-risk to direct damage or to the indirect impacts of wildland fire (utility services reductions, transportation restrictions, etc.).	16,460,689	$2,100,931,685
<u>Function of at-risk buildings</u>: Included in the state facilities potentially at-risk to wildland fires in the urban interface are the following: University of Washington’s Big Beef Creek Laboratory and Friday Harbor Marine Laboratory. Communication towers and facilities of the Washington Departments of Natural Resources, Transportation, and State Patrol. Ferry terminals at Southworth, Bremerton, Clinton, Keystone, Lopez Island, and Friday Harbor, and a variety of vehicle maintenance, storage and other facilities of the Department of Transportation. Lewis River, Tucannon, Mossyrock, Methow, Marblemount, and Arlington fish hatcheries, and facilities at a variety of wildlife and fishing access areas belonging to the Department of Fish and Wildlife. Campus of Echo Glen Children’s Center for juvenile offenders. Grandview and Toppenish armories of the State Military Department The Washington Veteran’s Home in Retsil. Picnic, comfort, shelter and other facilities at more than 30 parks operated by the State Parks and Recreation Commission.		
<u>Total at-risk critical facilities</u>: 732 state critical facilities were identified as being in the wildland fire-urban interface hazard zone potentially at-risk to direct damage or to the indirect impacts of wildland fire (utility services reductions, transportation restrictions, etc.).	1,451,630	$1,851,528,845
<u>Function of at-risk critical facilities</u>: Included in the state facilities potentially at-risk to wildland fires in the urban interface are the following: Lighhouses at Fort Casey and Limekiln State Parks. Pump houses, chemical storage, emergency generators, and other facilities at state parks, state fish hatcheries, and transportation department installations statewide. Communication towers and facilities of the Washington Departments of Natural Resources, Transportation, and State Patrol. Campus of Echo Glen Children’s Center for juvenile offenders.		

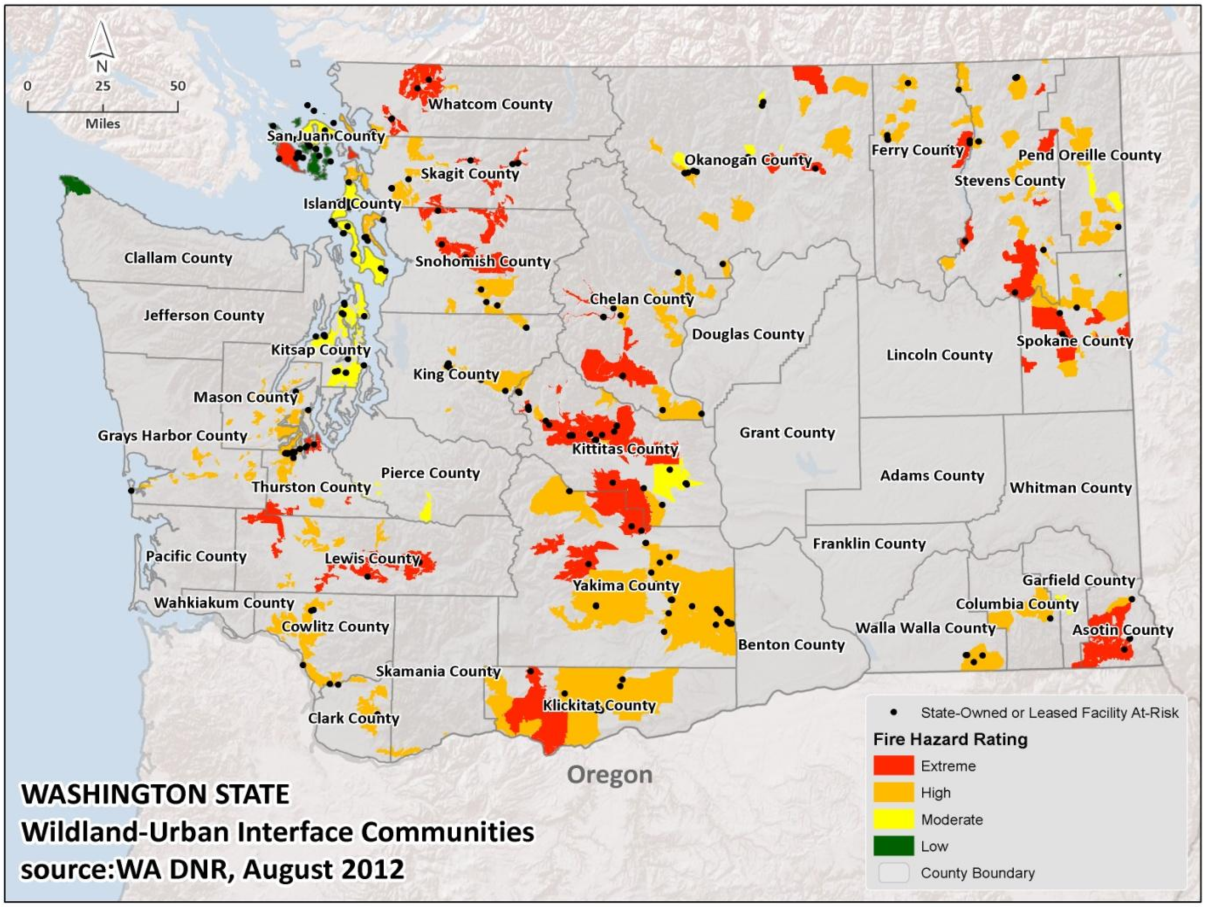


Figure 141 State-Owned and Leased Facilities in Communities at Risk

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